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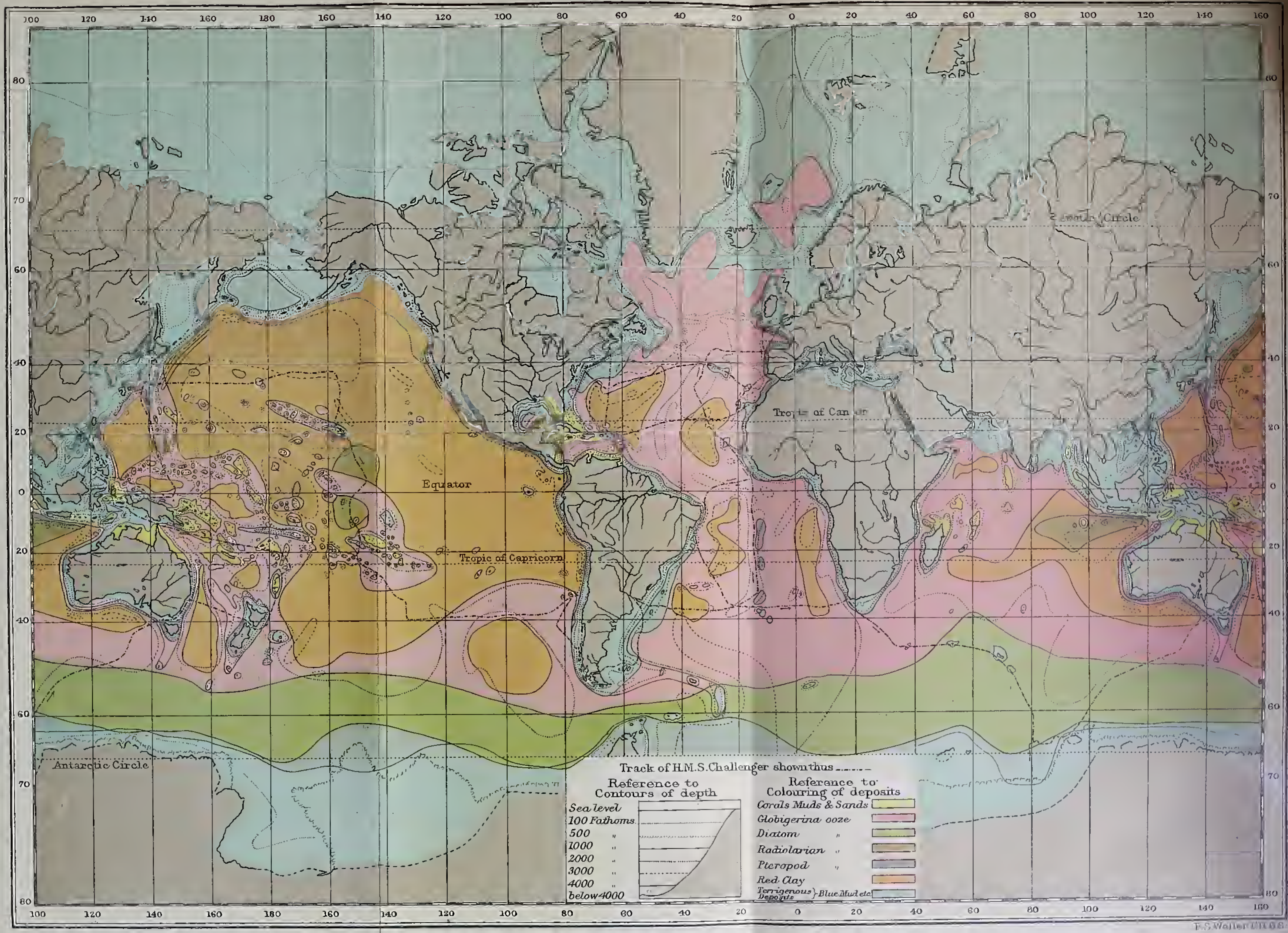

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ELEMENTARY PHYSIOGRAPHY

AN INTRODUCTION TO THE STUDY OF NATURE

BY

JOHN THORNTON, M.A.

HEAD MASTER OF THE CLARENCE STREET HIGHER GRADE SCHOOL, BOLTON
AUTHOR OF 'ADVANCED PHYSIOGRAPHY,' ETC.

WITH 12 MAPS AND 247 ILLUSTRATIONS

EIGHTH EDITION

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PREFACE.

THIS volume is intended to serve as an elementary introduction to Science. It supplies such a knowledge of the facts and laws of Nature as is implied in the expressive term *Physische Erdkunde*—an acquaintance with the physical phenomena of the earth.

The treatment is somewhat fuller than that adopted in some elementary books, as I believe that a meagre account, with a single figure, of such a subject as Volcanoes, for example, only leads to inaccurate and confused ideas. Numerous illustrations and maps have been introduced, as an aid both to the understanding and memory. Some of these have been drawn expressly for the book, while others have been derived from Rutley's 'Study of Rocks'; Helmholtz's 'Scientific Lectures'; Thorpe and Muir's 'Qualitative Analysis'; Peschel and Leipoldt's 'Physische Erdkunde'; Haughton's 'Lectures on Physical Geography'; Ganot's 'Physics'; Jago's 'Chemistry'; Reynolds's 'Chemistry'; 'Challenger Reports,' vol. xvi.; Chisholm's 'Geography'; Treglohan's 'Magnetism'; Ball's 'Astronomy'; Brinkley's 'Astronomy'; Proctor's 'Seasons.' The various instruments and apparatus regarded as indispensable by the Science Department, as well as others that are necessary for effective teaching, have been carefully described. The teacher is advised to make his lessons as much experimental as possible. Specimens of the various rocks and minerals may be obtained from several London dealers, and the pupils will readily gather a number of the commoner ones for themselves.

For some information on the Ordnance Survey and its maps

I am indebted to Lieutenant-Colonel T. P. White, R.E., Executive Officer of the Survey.

Among the books consulted in the preparation of this work may be mentioned: Ganot's 'Physics'; Professor Ball's 'Elements of Astronomy'; Dr. A. Geikie's 'Text-Book of Geology'; the treatises on 'Physical Geology' by Professor Prestwich and Professor Green; 'Histoire Naturelle des Pierres et des Terrains,' by Meunier; 'Volcanoes,' by Professor Judd; 'Elementary Meteorology,' by R. H. Scott; and the two volumes of the 'Challenger Reports,' entitled 'Narrative of the Cruise, with a General Account of the Scientific Results of the Expedition.' Other obligations are acknowledged in the pages of the book.

In conclusion, I beg to express my thanks to two or three friends for some assistance in reading over the proof-sheets.

JOHN THORNTON.

ALBERT PLACE, BOLTON:
February 1888.

PREFACE TO SECOND EDITION.

IN this edition a few corrections have been made and some additional matter brought in, but the numbering of the paragraphs is the same as in the first edition. Five new illustrations have also been introduced as well as a series of questions on Chapter XVI. With pupils wholly unacquainted with astronomical geography, it will be advisable to begin this chapter early in the course.

J. T.

THE THIRD EDITION contains a short account of recent researches on Dew, and gives a simple explanation of Telescopes.

PREFACE TO FIFTH EDITION.

In this edition I have added, at the request of several teachers, a set of questions on each chapter. I have also extended the portion of the appendix referring to some of the common astronomical instruments and their uses. The most recent examination papers of the Science Department are also included.

JOHN THORNTON.

Bolton:
January 1892.

PREFACE TO SEVENTH EDITION.

This edition has been carefully revised, and includes, among other additions, a fuller account of Deep Sea Deposits, derived from a recent volume of 'Challenger Reports.' By permission of the Controller of Her Majesty's Stationery Office, illustrations of the Deposits have been given, as well as a Coloured Map showing the extent of the deposits. The account of the Movements of the Earth has been largely rewritten and extended.

J. THORNTON.

Bolton:
September 1894.

PREFACE TO EIGHTH EDITION.

Several changes have been made in this edition consequent on the revised syllabus issued this year. This syllabus is reprinted in the Appendix, and may serve as a useful guide for students preparing for examination. The new astronomical points will be found fully dealt with in Chapter XVII., where some paragraphs not now required have been omitted to make room for this new matter. The fundamental principles of Mechanics, now included in the syllabus, are treated of in the Appendix, and may be read in connection with Chapter II.

J. THORNTON.

September, 1895.

CONTENTS.

PAGE

INTRODUCTION 1

CHAPTER

I. MATTER AND ITS PROPERTIES 3

II. GRAVITATION AND SPECIFIC GRAVITY—COHESION AND CHEMICAL AFFINITY 7

III. WORK AND ENERGY 17

IV. HEAT 20

V. CHEMICAL ACTION 32

VI. ROCKS — THEIR COMPOSITION, CLASSIFICATION, AND ARRANGEMENT 44

VII. INTERIOR OF THE EARTH—VOLCANOES—EARTHQUAKES AND OTHER MOVEMENTS OF THE EARTH'S CRUST 78

VIII. THE SEA 96

IX. THE POLAR REGIONS AND THE ICE OF THE SEA . 123

X. THE ATMOSPHERE 131

XI. EVAPORATION AND CONDENSATION—DEW, MIST, FOG, RAIN, AND SNOW 150

XII. THE SCULPTURE OF THE LAND 162

XIII. WEATHER AND CLIMATE 192

XIV. GENERAL IDEAS OF THE CHANGES WHICH THE EARTH'S SURFACE HAS UNDERGONE . . 199

XV. MAGNETISM AND ELECTRICITY OF THE EARTH . 210

XVI. THE SHAPE AND MOVEMENTS OF THE EARTH . 223

XVII. TELESCOPES—LIGHT, SUN, MOON, ECLIPSES—THE CELESTIAL GLOBE, ETC. 287

APPENDIX—MECHANICAL PRINCIPLES, NOTES, ETC. 311

QUESTIONS 326

SYLLABUS 337

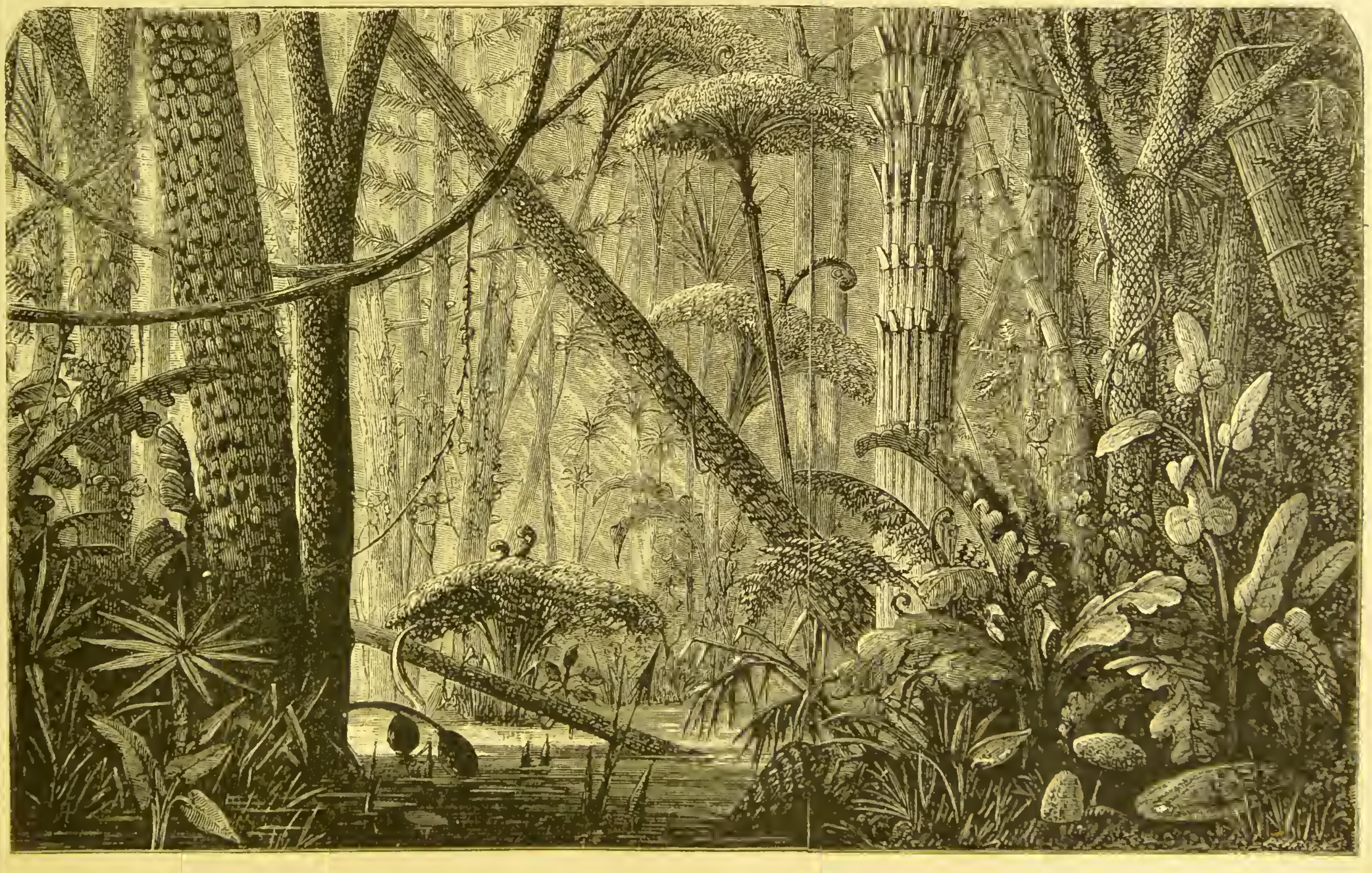
EXAMINATION PAPERS 339

INDEX 347

MAPS.

COLOURED MAP, SHOWING OCEAN DEPOSITS AND DEPTHS *Frontispiece*

MAP		PAGE
I.	DISTRIBUTION OF VOLCANOES AND EARTHQUAKES . .	91
II.	COASTS UNDERGOING ELEVATION AND SUBSIDENCE, AND DISTRIBUTION OF CORAL ISLANDS	95
III.	ATLANTIC OCEAN, SHOWING DEPTHS	104
IV.	THE WORLD, SHOWING OCEAN DEPTHS	107
V.	DISTRIBUTION OF ATMOSPHERIC PRESSURE OVER THE WORLD IN JULY	139
VI.	DISTRIBUTION OF TEMPERATURE OVER THE SURFACE OF THE EARTH IN JANUARY	144
VII.	DISTRIBUTION OF TEMPERATURE OVER THE SURFACE OF THE EARTH IN JULY	145
VIII.	MEAN ANNUAL RAINFALL OF THE EARTH	157
	JOINT DELTA OF GANGES AND BRAMAPUTRA . . .	169
IX.	MAP OF THIRLMERE VALLEY, SHOWING CONTOURS AND HACHURES	191
X.	THE ATLANTIC OCEAN, SHOWING CURRENTS . . .	197



CARBONIFEROUS FOREST (CARBONIFEROUS PERIOD), SHOWING PLANTS FROM WHICH COAL HAS BEEN FORMED

ELEMENTARY PHYSIOGRAPHY.

INTRODUCTION.

1. PHYSIOGRAPHY (Gr. *phusis*, nature ; and *grapho*, I write), according to its derivation, is a Description of Nature. The word *Nature* is used in several meanings, but in this connection it may be taken to stand for the general system of created things, including their constitution and properties. All the objects and facts belonging to this material world on which we live, as well as the objects and facts belonging to the other worlds that occupy space, are included in the word 'Nature.' Hence we may say that the word 'Nature' stands for the world and all upon it, or even for the universe. The sun, moon, and stars ; the sky, the clouds, and the wind ; the sea, the shore, and the rocks ; the mountains, plains and valleys, plants and animals, are all comprised in the term 'Nature' or 'Natural Objects.' Even what are called Artificial Objects are only natural things shaped and altered by the art of man.

2. By the use of our senses and by the action of our mind we learn what the different objects of the world are, and what are the different properties or qualities that these objects possess. In this way we arrive at ideas of cause and effect ; for we say that such an object is the cause of the sensation or effect that we observe. The fall of a stone when unsupported, and the formation of a cloud in the air, are effects, and it is our aim to find out the cause or reason of these *phenomena*. (The Greek

word *phenomenon*, plural *phenomena*, is used to signify appearance, object, or occurrence.) We have all a tendency to seek after causes, and when we have discovered the cause or reason of any frequently occurring phenomena we are said to have *explained* them. This explanation or statement of the general cause of certain effects is often called a Law of Nature. Thus it is a law of nature that an unsupported body falls to the ground ; it is a law of nature that at the ordinary summer temperature of the air water is a liquid, but that when the temperature falls below a certain point it becomes a solid. Accurate and systematic knowledge of the various laws of nature forms what is called Science ; and this is acquired by careful observation, experiment, and reasoning.

3. Now the study of nature is a very wide and extensive study, and although all knowledge is connected, yet for the sake of convenience it is divided into various branches or departments. Among these branches or sciences we have *physics*, *astronomy*, *chemistry*, *geology*, and *biology*. The physical sciences are often spoken of under the term Natural Philosophy, and embrace *mechanics*, which treats of force and motion, and the sciences of *heat*, *light*, *electricity*, and *magnetism*. *Astronomy* is the science which treats of the heavenly bodies, and among other things gives an account of the earth as a member of the solar system ; *chemistry* deals with the composition of substances and the combinations of different kinds of matter ; *geology* furnishes information regarding the arrangement and history of the materials forming the crust of the earth ; while *biology* or *natural history* gives an account of the phenomena of life both vegetable and animal, the account of vegetable life constituting the science of *botany*, and the account of animal life being called *zoology*.

It is plainly impossible to give in one small book anything like a complete account of these different sciences. But we can endeavour to learn some of the most important facts and laws from those that come under our daily notice. Such a rudimentary course of instruction in science, such a general description and explanation of common natural phenomena, is what is meant by ELEMENTARY PHYSIOGRAPHY.

CHAPTER I.

MATTER AND ITS PROPERTIES.

4. **Matter.**—*Matter* is the name given to anything that can affect any of our senses, to anything that possesses weight, to anything that can receive or communicate motion. The stones, soil, and grass on which we walk, the water or other liquid that we drink, the gas we burn, and the air we breathe, are all forms of matter or material things. Although we cannot see the air, we can feel it, and it often exerts so much force when in motion that it carries away or blows down the visible objects before our eyes. The words *thing*, *object*, *body*, *substance*, are sometimes used instead of the word matter.

5. Every material object possesses certain qualities or properties. We learn these properties by the use of our senses, the senses being sometimes assisted by suitable instruments. If we take up a pebble from the bed of a stream or from the sea-shore and examine it, we find that it is grey (or some other colour), that it is of a certain size, that it is round, that it is hard, that it will not burn, and that it will break into pieces. We then say that it possesses the properties of roundness, hardness, incombustibility, divisibility, &c. Now examine in the same way a piece of bread. It takes up space like the pebble, and will break into pieces, but it is soft, it will burn, and it is full of little visible holes or pores. Hence we see that hardness, whiteness, combustibility, &c., do not belong to all kinds of matter, but only to some kinds. We call these properties *specific* properties, but those qualities which belong to *all* matter are called *general* properties of matter. General properties, then, are those which are common to all bodies, whether in the solid, liquid, or gaseous state. The most important of these general properties of matter are Extension, Impenetrability, Divisibility, Porosity, Inertia, and Weight.

6. **Extension** is the property which matter possesses of occupying space. It means that an object has size and shape; that it possesses length, breadth, and thickness.

7. **Impenetrability** is that quality of matter in virtue of which it takes up room to the exclusion of other matter. It means that two bodies cannot take up the same space at the same time. Strictly speaking, this property only applies to the molecules or smallest particles of bodies.

8. **Divisibility** means that all bodies can be divided into smaller parts. We can break a stone into pieces, and then crush these pieces into powder. Gold is so malleable that it can be beaten out into leaves so thin that it takes 300,000 to produce the thickness of an inch. A lump of sugar may be dissolved in a gallon of water, and yet a portion of it exists in every drop. The microscope teaches us that chalk is made up of very small shells, and that each of these shells is built up of minute particles which the chemist calls calcium carbonate. Notwithstanding this extreme divisi-

bility we believe that there is a limit to this property. When we come to consider chemical action we shall see that there is reason to believe that all the elementary bodies are composed of extremely minute indivisible parts called *atoms*, and the term *molecule* is given to the smallest cluster of atoms composing any substance which can exist by itself.

9. **Porosity.**—Many bodies, like bread, pumice-stone, coral, sponge, cork, &c., have visible spaces or intervals between the particles of which they consist. These spaces or interstices are called *pores*. Sometimes the pores can be seen with the unassisted eye, as in the above ; at other times the aid of a microscope is needed, or some experiment must be made to prove that pores exist in a body. If a piece of chalk be thrown into water, air bubbles rise to the surface, the air being driven out of the pores by the water absorbed. And since all bodies are compressible, that is, can be made to diminish in volume, and since contraction or expansion results from variations of temperature, it is believed that there are vacant spaces between the constituent molecules of all matter. In the chapter on *Heat* we shall learn that the volume of bodies can be more easily diminished by cooling than by pressure. Gases are the most compressible bodies, solids the next, and liquids the least compressible. This property of porosity is made use of in the process called *filtration*. This consists in separating from liquids the various solid particles which they hold in *suspension*. These particles are too large to pass through the pores of the filter, which is usually constructed of layers of sand, compressed charcoal, unsized paper, &c. Deep well water is clear because it has been filtered through layers of earth.

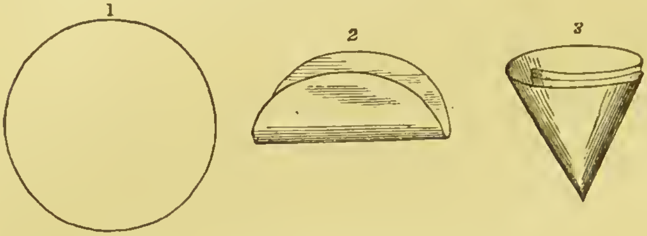


Fig. 1.—Mode of folding a Filter Paper.

10. **Experiments on Filtration and Evaporation.**—Take up a glass of turbid water from a stream or well and let it stand for a time ; we find that some of the muddy particles settle as a sediment on the bottom of the glass. The clearer water can then be poured off, or *decanted*, as it is called. But this method of decantation does not often render the liquid quite clear, for some of the lighter solid particles still remain suspended in the water. Now take a flower-pot, and into the hole at the bottom place a piece of cork through which a small piece of glass tubing just passes. After placing a small piece of sponge on the inside over the tube, put in a layer of small pebbles, and then half fill the pot with clean white sand. Now take up some muddy water and pour it on the sand. In passing through the pores between the particles of sand the suspended mud gets separated, and the water runs out clear. If we could fit a piece of chalk or sandstone tightly into the flower-pot, water might be filtered through it.

But the chemist usually filters in the following way. He takes a circular piece of unsized filter-paper, and, after folding it twice, opens it out into a cone, so that three folds of paper are on one side and one on the other. He then places it into a glass funnel, and pours the liquid on the filter down a glass rod. In this way all the solid particles in suspension are removed and left behind on the filter-paper, and the liquid runs through the pores of the paper and comes out clear. This clear liquid is called the *filtrate*.

11. **Evaporation.**—It must be carefully noted that the process of filtration only removes the solid particles held suspended in the liquid. If the water hold any substance in solution, this is not removed by filtering. Take some sand and common salt, or powdered chalk and salt, and stir up in a glass of water. The salt dissolves, and the sand or the chalk does not dissolve. On filtering, we can remove the sand or the chalk which will be left on the filter-paper, but the clear liquid that runs through still tastes salt. To separate the salt from the water we must pour the liquid into a small china basin such as the chemist uses, and apply heat. The water will be driven off as steam, and the salt will remain behind in the basin. In this way we have learnt (1) that the solid particles held in suspension in water may be *partly* removed by letting the water stand still, so that the heavier particles may settle as a sediment; (2) that *all* the suspended matter may be removed by careful filtration; (3) that the matter *dissolved* in the water cannot be removed by filtration, but that it may be recovered by evaporation.

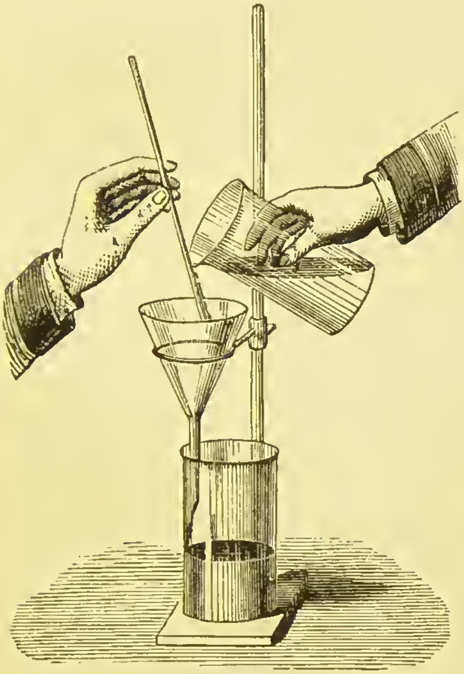


FIG. 2.—Method of Filtering.

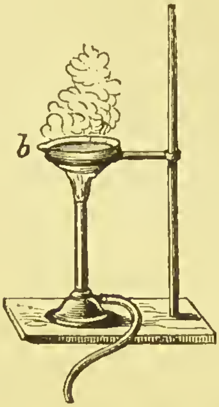


FIG. 3.—Evaporation to recover Dissolved Matter.

12. **Inertia** (Lat. *iners*, inactive), or *vis inertiæ*, is the name given to that negative quality of matter whereby it is incapable of changing its state of rest or motion; of itself it cannot either begin to move, or change either the speed or the direction of its motion if it has any. The body of course is understood to be lifeless. This property is sometimes spoken of as Newton's first law of motion, or the law of inertia. It may be stated thus:—

> 'When a body is not acted upon by any external force, if it be in a state of rest it will continue so, and if it be in motion it will continue to

move in a straight line with uniform speed.' Our daily observation shows us that when anything is at rest it does not begin to move of itself. Sometimes a body in falling down appears to move of itself. This is not so; for, as we shall presently see, it is acted on by a force called gravity. A little consideration, too, will enable us to see it will continue to move uniformly unless acted upon by some external force. A cricket ball sent rolling along the grass soon comes to rest, on account of the resistance it meets with in passing through the air and over the uneven surface. Send it along a smooth sheet of ice and it goes further still, and keeps the same direction unless turned aside by some obstacle. Replace the cricket ball by a smooth ball of ivory of the same weight, and it goes still further, because the resistance of friction is less. The more we diminish the resistance, the longer and further does the ball travel in the same direction; and thus we may conclude that if all resistance were removed, the motion would continue in the same direction for ever. Bodies are said to be at *rest* when they constantly keep the same position in space; they are said to be in *motion* when they are undergoing a change of position. But no body is absolutely at rest. The earth and its atmosphere together form one body, and it is at the same time turning on its axis and moving round the sun. Thus all bodies on the earth may be said to be in motion. But when bodies are said to be at rest, it is usually meant that they maintain the same position in relation to the other objects on the earth's surface. In this sense a house or a tree is at rest, while a moving cricket ball or a galloping horse is in motion.

Illustrations of Inertia.—If a man be riding in a carriage which suddenly stops, he is thrown forwards, because he continues in his state of motion after the carriage itself has stopped. If he be on horseback and the horse start off suddenly, the man falls backwards, because of the tendency to preserve his state of rest. A horseman on suddenly turning a corner leans towards the corner, in order to prevent being thrown off in the direction of his previous motion. If we wish to jump over a small brook we take a run, that the onward motion of our bodies may be added to the muscular effort that we make at the moment of jumping.

13. **Weight.**—The last of the general properties mentioned was *weight*. Although we speak of heavy bodies and light bodies, yet the difference is only one of degree. All bodies have weight, but some have much more than others when we compare them bulk for bulk. A piece of iron is much heavier than a piece of wood of the same size. Gases like the air have weight. A hollow glass globe holding a cubic foot weighs nearly an ounce and a quarter more when it is full of air than it does when exhausted of air. Now the weight of a body is only the result of the earth's attraction on the particles of the body. There is an invisible force which the earth exerts on all bodies, by which it attracts or draws them towards itself. This attraction, called gravity, gives rise to the *weight* of a body which is supported, and to the *fall* of a body which is unsupported; and we call this attraction the attraction of gravitation (Lat. *gravitas*, weight). Hence we see that the weight of a body is its downward pressure caused by the force of gravity.

Until the time of Newton this property of gravitation was only considered as belonging to the earth. But he extended the idea, and showed that not only did the earth attract bodies towards its centre, but each body exerted a pull on the earth. Further, Newton showed that all bodies in the universe attract one another; the earth attracts the sun and the moon, and the sun and the moon attract the earth. Hence it was found that every particle of matter in the universe attracts every other particle, and thus *gravitation* was shown to be *universal*. We will now proceed to discuss this force more particularly, and to state the laws of its action.

CHAPTER II.

GRAVITATION AND SPECIFIC GRAVITY—COHESION AND CHEMICAL AFFINITY.

14. **Gravitation.**—In order to understand the laws of gravitation it is necessary to get clear ideas of some of the terms used in stating the laws. Hence we proceed to make a few definitions.

Force is any cause which changes or tends to change a body's state of rest or motion. It is measured by the number of units of force (one pound) that it will sustain. Forces may be represented in magnitude and direction by straight lines. Force has a twofold nature, being always the mutual action of *two* bodies against one another, and the amount of the force is exactly equal to the amount of resistance. We therefore say that action and reaction are equal and opposite.

Density means the closeness with which the particles of a body are packed together. As the density depends on the weight of the molecules composing a body, and on the compactness or closeness of these molecules, the specific gravity is in proportion to the density, and may be taken as a measure of the density.

Volume or magnitude is the amount ot space occupied by a body.

Mass is the quantity of matter contained in a body, and varies as the product of the volume and density of a body.

15. We have seen that gravitation is universal, that is, that every particle of matter in the universe attracts every other particle. Let us confine our attention to the mutual attraction of the earth and the bodies on or near its surface. This is sometimes called *terrestrial* gravity, or simply gravity ; the term gravitation being applied to the attraction exerted between the heavenly bodies. It is a particular case of universal attraction.

16. If every particle attract every other particle, why do we not see two suspended balls come together ? The reason is that the attractive force of the earth on the balls is so very great compared with that of the balls on each other, that this latter is not perceptible. But if only these two balls existed in the universe they would begin to approach one another, and would finally meet. This leads us to the first part of the law of gravitation —*The force of gravitation varies directly according to the product of two masses.* This is plain; for if every particle exert its attractive influence, the more particles a body contains the greater will be the attraction. A body which contains twice as much matter as another is attracted or drawn

towards the centre of the earth with twice the force—that is, it will have twice the weight of the other; if its mass be five times as great, then it will be attracted with five times the force, that is, it will have five times the weight of the other. Hence we see how it is that the earth exerts such an overwhelming attractive force as to draw all bodies towards its centre, its mass being so very great compared with that of any single body on its surface. If the mass of the earth were only half what it is, its attractive force would only be half as great; on the other hand, if the mass of the earth were twice what it is, then the attraction of gravitation at its surface would be twice as great. It may be said that such things as smoke, vapour, and balloons filled with light gas ascend. They do this simply because they are lighter, bulk for bulk, than air, and therefore the earth attracts the air with greater force than it attracts the lighter bodies, and the heavier air pushes them up until they reach a layer of air of the same density as themselves. For the same reason a piece of cork, when held under water and then released, rises to the top.

17. The second part of the law of gravitation teaches us that *the force of gravity varies inversely as the square of the distance.* This means that if for any two bodies the distance be doubled, the attraction between them is diminished four times; if the distance be trebled, the force of attraction is diminished nine times; if the distance be increased ten times, the force of attraction is diminished one hundred times; and so on.

$$2^2=4, \text{ and invert}=\tfrac{1}{4};\ 3^2=9, \text{ and invert}=\tfrac{1}{9};$$
$$10^2=100, \text{ and invert}=\tfrac{1}{100}.$$

18. Since the attractive force of the earth must be calculated from its centre, and since the equatorial diameter of the earth is greater than the polar diameter, the force of gravity at the poles must be greater than at the equator, bodies there being at a less distance from the centre.

Thus, in the figure, O E is greater than O C, and still greater than O P. There is also another reason why the attractive force is greater at the poles. The rotation of the earth on its axis gives rise to a centrifugal force which tends to drive bodies off its surface. Now this centrifugal force decreases as we get

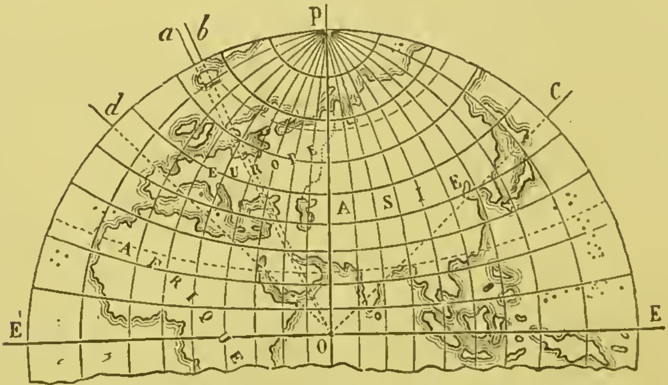


FIG. 4.—Showing Polar Radius P O less than Equatorial Radius E O or E′O, also showing direction of vertical lines *d* O, *a* O, *b* O, and C O.

nearer the poles, the velocity there being less. Hence the weight of a body increases as we pass from the equator to the poles. This increase could not be detected by an ordinary balance, for gravity would act in the same way on both the weights and the body to be weighed. It can be detected by a delicate spring balance, called a *dynamometer*, for the given mass would cause the spring to move through a greater distance at the poles than at the equator.

19. The direction taken by a body falling freely towards the earth is called the *vertical*, and the vertical lines at different points of the earth's surface when prolonged meet at the centre (see fig. 4). But, owing to the great distance of the surface from the centre, these verticals may be considered parallel for points situated close together as at *a* and *b*. But the further the points are apart the more do the lines depart from being parallel, till, as the earth is spherical, at points exactly opposite the two lines are in inverted positions. Places on the surface of the earth diametrically opposite each other are called antipodes (Gr. *anti*, against; and *pous*, *podos*, foot). A mason finds the vertical line by letting a plumb-line or plummet (which is only a cylindrical weight fastened to a string) come to rest under the action of gravity. The surface at right angles to the vertical is said to be horizontal. The surface of still water is horizontal.

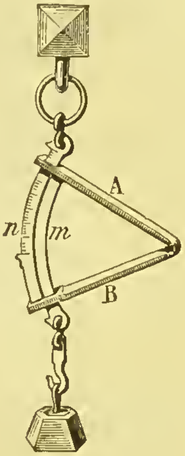


FIG. 5. Dynamometer.

20. We may now state the law of gravitation as follows :—'*Every particle of matter in the universe attracts every other particle with a force whose direction is that of the line joining the two, and whose magnitude is directly as the product of their masses, and inversely as the square of their distance from each other.*' Thus if the mass of one body be six times a certain unit, and the other body nine times, the whole attraction would be represented by $6 \times 9 = 54$; but if the distance were increased three times, the attraction would then be represented by $\frac{6 \times 9}{3^2} = 6$.

21. *All bodies fall in a vacuum with equal velocity.* This must be so according to the law just stated, for if gravity pulls at a ten-pound weight with ten times the force that it pulls at a one-pound weight, yet it has ten times as much matter to move. It was at one time thought that a ten-pound weight would fall to the ground ten times as fast as a one-pound weight, that two bricks fastened together would fall twice as fast as one of the same size. But the Italian philosopher Galileo took bodies of different weight and of about the same density to the top of the tower of Pisa, and

showed that they reached the ground at the same time as nearly as possible when let fall together. It is true that if we take a feather and a sovereign and let them fall from a height together, the sovereign reaches the ground first. But this is due to the greater resistance of the air on the feather, for it is much larger than the coin compared with its weight. If, however, we take a tall jar and exhaust the air by means of an air-pump, and then contrive to drop the coin and the feather from the top of the jar at the same time, they will reach the bottom at the same time.[1]

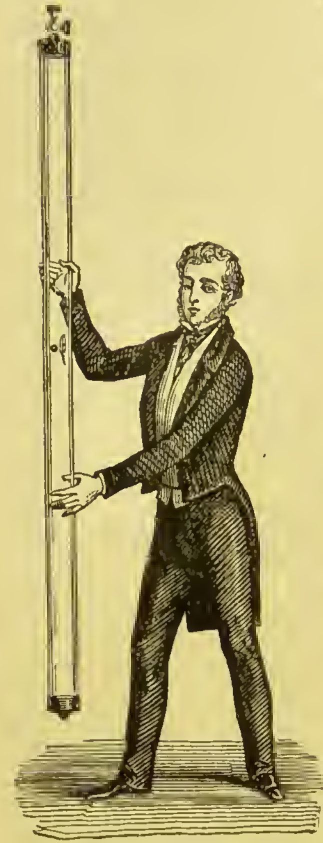


FIG. 6.—A Feather and a Sovereign falling in a vacuum with equal velocity, owing to the action of gravity.

22. **Specific Gravity.** — Specific gravity means comparative weight. We often speak of bodies as *heavy* and *light*. Thus we say that iron is a heavier substance than cork. Here there is evidently some *comparison* implied, for we do not mean that a small iron ring is heavier than a large strip of cork. We mean that taking them bulk for bulk, that is, comparing pieces of equal size or volume, iron is heavier than cork. Now it is convenient to have some substance as a standard or measure with which others may be compared, and the most convenient substance to take as a standard is pure water. This can be obtained by distillation, that is, by boiling the water and then collecting and condensing the vapour by cooling. Here is the apparatus for obtaining pure distilled water (fig. 7). A is a stoppered retort, the neck of which passes into a Liebig's condenser B. This consists of an inner tube of glass *g*, passing watertight through an outer tube or jacket *j*. The lower end of the inner tube *g* passes into a glass receiver C. Water is placed in the retort A and a lamp applied. After a time the water boils vigorously, and the steam passes into the inner tube *g* of the apparatus of Liebig. Here it is condensed by a stream of cold water that enters the outer tube of the condenser at the funnel *f*. This stream cannot mix with the condensed steam, but is carried away by the tube *t* placed at the upper part of the condenser. The condensed steam or distilled water drops down and is collected in the receiver C, and the water thus obtained is chemically pure, all the dissolved matter being left behind in the retort. The distillation should be discontinued when the water in the retort has been reduced to about one-fifth its original bulk. The pure water thus obtained is a colourless, inodorous, insipid liquid. When pure water, however, is seen in large masses it has a faint bluish colour.

The water, too, must be taken at a certain temperature in order that a given volume may always have a certain weight; for, as we shall soon learn, the bulk or volume varies when the temperature changes. Having thus agreed to take pure distilled water at 39° F. as the standard substance, we call a certain volume of this water unity, and compare the weights of other substances with the weight of an equal bulk of such water.

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[1] On *Momentum*, see note in Appendix, p. 251.

We can then define specific gravity as follows :—

The specific gravity of a substance is the number which expresses the weight of a certain volume of the substance compared with the weight of an equal volume of distilled water. Thus when we say that the sp. gr. of lead is 11, that of diamond 3·5, and that of cork ·24, we mean that lead is eleven times, that diamond is three and a half times, and cork only about one-fourth as heavy as water (comparing equal bulks).

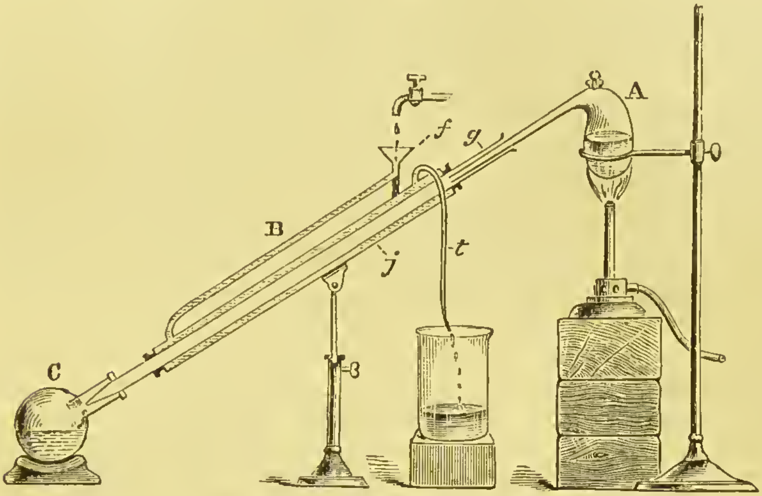

FIG. 7.—Apparatus for obtaining Pure Distilled Water.

23. The following table gives the specific gravities or densities of a few of the most important substances : 1, solids ; 2, liquids :—

Specific Gravities of Solids.

Platinum	22·07	Marble	2·80
Gold	19·35	Aluminium	2·68
Lead	11·35	Rock-crystal	2·65
Silver	10·50	Salt	2·13
Copper	8·90	Coal	1·32
Iron	7·80	Ice	·93
Heavy spar	4·43	White fir	·57
Diamond	3·50	Cork	·24

Specific Gravities of Liquids.

Mercury	13·60	Distilled water at 39° F.	1·00
Bromine	2·96	Distilled water at 32° F.	0·99
Sulphuric acid	1·84	Olive oil	·91
Milk	1·03	Alcohol	·80
Sea water	1·02	Ether	·72

By means of the above table we can find the weight of a given volume of any of these substances, having given that a cubic foot of water weighs

1,000 ounces. Thus we see from the table that a cubic foot of copper will weigh 8,900 ounces, a cubic foot of marble 2,800 ounces, but a cubic foot of ice only 930 ounces. Sea water, however, is bulk for bulk heavier than ordinary water, for a cubic foot of sea water weighs 1,020 ounces.

24. **Cohesion and Chemical Affinity.**—The attraction of gravitation, which we have been considering, is the force which, acting at any distance, binds the larger masses of the universe into worlds, keeps the earth in its orbit round the sun, draws all the various objects towards its centre so that they remain on its surface, and brings together but does not bind the different particles or molecules of a body. Now there are two other permanent forces acting on matter, called cohesion and chemical affinity.

25. *Cohesion* is an attractive force, but it is only exercised between similar molecules of matter, and at insensible distances. Cohesion binds molecules of the same substance together so as to form masses, and it is on account of this force that bodies keep their shape and resist being broken. Were it not for the force of cohesion everything would be reduced to extremely fine powder. The force of cohesion is greatest in solids ; it is only weak in liquids, though sufficient to keep the small masses called drops in a globular form : in gases it does not exist at all, as their particles tend to spread in all directions. In solids the force of cohesion varies greatly, as we learn when we try to break them. It is very strong in a piece of iron, weaker in a piece of wood, and still weaker in a piece of salt.

26. *Chemical affinity* is an attractive force which, like cohesion, only acts at insensible distances, but unlike cohesion it is exerted between dissimilar particles. Chemical affinity is the force which binds together the particles of different substances, so as to form an entirely new substance with different properties. A chemical change is always a change of composition. It is the business of the chemist to examine the various substances he finds, with a view of resolving them into their ultimate *elements*. From this examination we learn that all bodies are made up out of sixty-five elements, an element being a substance which cannot be split up into two or more different substances. The numerous different substances in the world are produced from the union of these elements in various ways, just as the thousands of different words in our language are formed by uniting in various ways the twenty-six letters of the alphabet. It is the force of chemical affinity which unites these elements so that new substances are produced ; and the more dissimilar the elements, the more readily do they unite as a rule.

27. **Atoms and Molecules.**—An *atom* is the smallest particle of an element that can enter into chemical combination or be driven out of a compound. A *molecule* is the least portion of any substance, whether simple or compound, that can exist in a free state and possess all the properties of that substance. A molecule of a compound must contain at least two atoms, and it often contains more. The atoms of the elements can never be destroyed. They may enter into new combinations, but even

when they form invisible gases they still exist as matter. Matter is therefore said to be indestructible.

A piece of white sandstone consists of innumerable grains of sand compacted and cemented together, the particles of the mass being held together by the force of cohesion. Each grain of sand consists of numerous minute molecules of a substance called silica, also bound together by the force of cohesion; and each molecule of silica contains two elements, being composed of two atoms of the element oxygen, and one atom of the element silicon, bound together by the force of chemical affinity.

In a piece of common salt the force of cohesion is much less, as the piece can be so easily broken. Each smallest particle or molecule of salt is formed by the union of the two elements sodium and chlorine, one atom of sodium being chemically combined with one atom of chlorine.

Hence we see that *gravitation* binds together the larger masses of the universe, and that terrestrial gravity, which is only a particular case of universal gravitation, tends to draw all substances towards the centre of the earth; that *cohesion* holds together the *molecules* of the same substance so as to give things their form and consistency; and that *chemical affinity* unites the atoms of different elements so as to produce new substances. Gravitation acts at all distances; cohesion and chemical affinity only when the particles are in close contact.

28. **Adhesion** is the name given to that force which causes the *surfaces* of two different bodies to stick together. Unlike cohesion, it can act between dissimilar bodies. Two smooth plates of glass, or a smooth plate of glass and one of brass, on being brought into close contact, adhere with considerable force.

29. **Solids, Liquids, Gases.**—All the substances in nature exist in one or other of these conditions, and many substances present themselves at different times under all these three forms. Thus it is one and the same substance which is known to us under the names of ice, water, and steam; for ice, water, and steam have the same chemical composition, each molecule consisting of two atoms of the gas hydrogen united to one atom of the gas oxygen. The element mercury (quicksilver), which is usually a liquid, can be frozen by great cold, and can be turned into vapour at a high temperature.

Wood, silver, stone, &c., are solid bodies; water, mercury, oil, &c., are liquid bodies; and oxygen, air, &c., are gaseous or aëriform bodies. Liquids and gases are both termed fluids. The word *vapour* is generally applied to those gases which are obtained from bodies that are liquid at the ordinary temperature.

These three states in which bodies occur are called their *states of aggregation.*

Solid bodies have a definite shape, and occupy a definite volume, *i.e.* take up a definite amount of space. Liquid bodies have no definite shape, though they occupy a definite volume. They take the shape of any vessel into which they are poured. Gaseous or aëriform bodies have neither definite shape nor definite volume.

In solids the force of cohesion is strong. Solid bodies are sometimes called *rigid* bodies, because their particles keep the same position, and because they resist change of form. In liquids the cohesion is only slight, and the particles move easily among themselves. The globular form taken by drops of water is due to the cohesion among the molecules of the liquid, and the small particles in the thin film of a soap bubble are held together by the force of cohesion. In some liquids, such as alcohol and ether, the particles move over one another more freely. Such a liquid is called a *mobile* liquid. In other liquids, such as treacle, glycerine, and melted glue, the force of cohesion is greater than in water, and they move along a surface more slowly than water. Such a liquid is called a *viscous* liquid.

Between the molecules of gases there is no cohesion at all, for the particles repel each other and spread themselves out in all directions, so that any quantity of gas, however small, spreads itself out so as to fill any space.

By the application of heat the cohesion of solid bodies is so far destroyed that the liquid state is assumed ; and a further application of heat destroys the cohesion altogether, so that the molecules are driven still further apart, and the gaseous state is assumed. Hence heat is sometimes spoken of as a repulsive power, opposite in character to that of cohesion.

It must be remembered that a gas or vapour occupies a very much larger space than the liquid from which it was derived. One cubic inch of water, on being heated to boiling, yields 1,700 cubic inches of water vapour at 212° F. (100° C.). (See section on Heat.)

30. **Solution and Crystallisation.**—Some solid substances, such as salt, saltpetre (nitre), alum, &c., when put into a liquid such as water, become liquid themselves, and their particles are so minutely divided as to be altogether invisible, even under the microscope. The substance is then said to dissolve. The solubility of solid substances varies very much. Some will not dissolve at all in water, some dissolve very slightly, and others dissolve in considerable quantity. As a general rule, the hotter the water, the more of a substance can it dissolve. Some gases, too, such as carbonic acid, are soluble in water, and such water may then dissolve substances that are not soluble in pure water. When a quantity of a liquid has dissolved as much of a substance as it can at a certain temperature the liquid is said to be *saturated*, and the solution is called a *saturated solution*. As hot water will dissolve much more of a solid substance than cold water, on cooling a hot saturated solution some of the solid crystallises out. But we may always recover the solid dissolved by evaporating the solution. In most cases the solid will then assume a definite geometrical form, called a crystal. The molecules seem to possess a power of arranging themselves in regular and symmetrical order, so that definite geometrical shapes, such as cubes, prisms, pyramids, &c., are formed. As each substance has usually its own peculiar form, many substances can be at once distinguished by the shape of their crystals. Not only do crystals form from liquid solutions, but solid bodies, such as sulphur, bismuth, and many other minerals which have been melted or fused, form crystals when allowed to cool gradually.

Many hard rocks are seen to be composed of little crystals, but the crystals are so confusedly mingled that it is difficult to distinguish them. Such bodies are said to possess a *crystalline* structure. A piece of statuary marble possesses such a structure. In the crevices of rocks, however, the minerals have sometimes had room to form into distinct crystals. Snow and ice are crystallised forms of water. The snow crystals can be seen with the naked eye when snowflakes fall on any dark surface like the sleeve of a coat (see par. 226). Bodies which do not take a definite geometrical shape are said to be *amorphous* (Gr. *a*, not ; *morphe*, shape).

31. **Experiments on Solution and Crystallisation.**—(1) Dissolve some common salt in a tumbler in about twice its weight of water, stirring it well. Pour off the clear solution in a shallow plate and set it aside for a few days and do not disturb it. The water gradually evaporates, and small *cubes* of salt are formed. Look at these with a lens, and their shape will be more apparent.

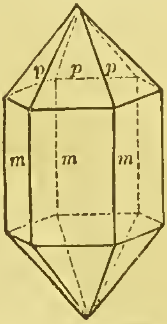

FIG. 8.—Form taken by Quartz Crystal. *p*, pyramid planes; *m*, prism planes.

(2) Dissolve some alum in about twice its weight of hot water. Put aside the solution to cool slowly; beautiful transparent octohedral crystals will then be formed, though it is not easy to get them perfect in all directions.

(3) Obtain a specimen of rock crystal. It is composed of mineral quartz, which is an oxide of silicon. Examine one of the crystals, and you will see that it consists of a six-sided column or prism capped with six-sided pyramids at each end (see fig. 8). It is rare, however, to find both ends perfect. Try to scratch the crystal with your knife ; it is too hard to scratch. It will itself scratch glass.

32. **Other Properties of Solids.**—*Stress and Strain.*—Stress is the name applied to any force or forces acting on a body and tending to disarrange the particles composing it. This stress is called a *tension* if the forces are acting away from each other, as in breaking a string ; it is called a *pressure* if the forces are acting towards each other, as in cracking a nut. *Strain* is the effect which a stress produces in a body before it breaks. Thus a beam in a building is said to undergo a strain if compressed, or stretched, or bent, or distorted in any way.[1]

33. *Tenacity* (Lat. *teneo*, I hold) is the resistance which bodies offer to being broken ; that is, the resistance they offer to any force tending to tear their particles asunder. It is usually tested by forming the substance into wires, and attaching weights to the wires until they break. Steel has the greatest tenacity of any metal. Then come wrought iron, copper, platinum, and silver, in order.

Malleability is that property which enables substances to be beaten out into thin plates. Many of the metals possess this property. Gold is very malleable, leaves being made only $\frac{1}{300000}$ of an inch in thickness. Next to gold in malleability come silver, copper, platinum, iron, in order. The opposite property is brittleness.

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[1] More correctly, *stress* may be defined *as the mutual action between two portions of matter.* When we press upon a body with our hand, the hand is equally pressed back by the body ; and in every case, to the action of any force by one mass on a second mass, there always corresponds an equal and opposite reaction by the second mass on the first. A stress therefore consists of two equal and opposite forces which together form an action and a reaction. We often think of only one of the masses between which a stress is acting and of only one part of the stress ; and according to the mode in which the stress acts, it is described as attraction, tension, pressure, &c.

34. *Ductility* is a property closely allied to malleability, but the most malleable is not always the most ductile. This is the property in virtue of which substances are capable of being drawn out into fine narrow threads or wires. Gold, silver, platinum, iron, and glass (when melted) are the most ductile. Wires of platinum and gold can be obtained much finer than a spider's thread.

35. *Elasticity* is the property which enables bodies to recover their original shape when the external force which has altered their form is removed. Many solid bodies are elastic, but there is a certain limit (called the limit of elasticity) beyond which the body does not recover its shape, but is either distorted or broken. Great brittleness and elasticity may exist in the same substance. Hard steel and glass rods are very elastic within certain limits, but in lead the tendency to recover its shape is confined to a very small limit.

Liquids and gases are perfectly elastic, and regain their original volume, however great the pressure was to which they may have been subjected. Liquids are only compressible to a very slight degree, and on removal of the pressure they recover their former dimensions.

36. *Elasticity of Gases.*—Gases are the most compressible and elastic of all bodies. If a quantity of gas be enclosed in a cylinder fitted with an air-tight piston, it may be compressed by pushing down the piston. On the removal of this additional pressure the gas will regain its former volume. A hollow india-rubber ball rebounds in consequence of the elasticity of the air within it. As all gases are perfectly elastic, they all follow the same law. It is found that if we double the pressure the volume diminishes to one-half; if we treble the pressure the volume becomes only one-third. Hence was derived Boyle's law—*The volume of a gas varies inversely as the pressure to which it is subjected when the temperature remains the same.* It is plain that while the volume diminishes as the pressure increases, and *vice versâ*, the density must increase as the volume diminishes, and *vice versâ.*

Hence the law may be stated thus: *For the same temperature the density of a gas is directly proportional to its pressure.*

This law was until recently thought to be absolutely true. For very high pressures a deviation begins to be observed with some, but for ordinary experiments the law may be regarded as true. It should be remembered that all gases can be liquefied by pressure and cold.

37. *Hardness.*—In scientific language *hardness* is that property of bodies in virtue of which they resist being scratched by others. We test which is the harder of two bodies by seeing which of them will scratch the other. Diamond is the hardest of all substances, for it will scratch every other substance and is not scratched by any. A scale of hardness has been formed of the following series of minerals. Each of these scratches all those above it, and is scratched by all those below. If the substance we are examining is found to scratch felspar, but is found to be scratched by quartz, we say that its hardness is between 6 and 7. The first column gives the name of the mineral, and the last its chemical name. These latter names will be better understood after reading the section on chemical action.

38. *Scale of Hardness.*

Mineral		Chemical Name.
1. Talc . . .	can be scratched by the finger-nail	1. Magnesium silicate
2. Gypsum (or rock-salt) . . .		2. Calcium sulphate or Sodium chloride

Mineral		Chemical Name
3. Calc-spar	can be scratched by knife or file	3. Calcium carbonate
4. Fluor-spar		4. Calcium fluoride
5. Apatite		5. Calcium phosphate
6. Felspar		6. Potassium and aluminium silicates
7. Quartz (rock-crystal)	cannot be scratched by knife or file	7. Silica
8. Topaz		8. Aluminium fluosilicate
9. Corundum (sapphire, ruby)		9. These gems are crystallised alumina
10 Diamond		10. Crystallised carbon

CHAPTER III.

WORK AND ENERGY.[1]

39. In the science of Mechanics the word work is used in a peculiar sense. A force is said to do work when the body on which it acts is made to move. Merely supporting a weight is not doing work in this sense, for there is no work done unless the body is made to move in the direction of the force. Hence we may define *work* as the production of motion against resistance. It is *measured* by the product of the force into the distance through which the body moves in the direction of the force. The unit of work is the work done in moving one pound weight vertically through one foot, and this unit is ordinarily called a *foot-pound*. Hence, if we lift a weight of fourteen pounds through a vertical height of four feet, we perform fifty-six units of work. We thus express work in *foot-pounds* by multiplying the number of pounds in a given weight by the number of feet through which it is raised. The work done in raising a heavy body is done in overcoming the earth's attraction. Work is also done when we pull away a piece of steel held in position by the attractive force of a magnet, when we compress air, and, in general, when anything is caused to move in the direction of the force applied.

Energy is the term used to denote the capacity or power of doing work against resistance.

40. **Kinetic and Potential Energy.**—There are two kinds or forms of energy, which are called Kinetic and Potential. *Kinetic energy is the power of doing work which a body possesses by virtue of its motion.* Thus a bullet when in motion can do work by giving up its velocity. When it strikes a target its energy is not lost, but passes into the form of heat, and heat is believed to be a mode of motion of the ultimate particles or molecules of which a substance is composed. The *visible* moving energy of the mass is said to have been converted into *molecular* energy. Water when in motion possesses kinetic or actual energy, for it can be made to do work by turning a water-wheel. *Potential energy is the power of doing work which a body possesses by virtue of its position.* Thus, when a heavy body has been lifted to the top of a house, it possesses potential energy, for it can do work whenever it is allowed to descend to a lower level. A bent spring has potential energy, for it can do work as it changes its shape.

41. **Other Examples of Energy.**—Heat is regarded as a form of energy because it may be generated by the application of work, and because work

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[1] This chapter may be omitted on a first reading.

may be done by the action of heat. Moreover, a definite amount of work always produces a definite amount of heat, and the same number of units of heat always produce a certain fixed number of units of work. Every steam engine develops mechanical work out of heat; for heat turns the water into steam, and this water vapour by its effort to expand sets the wheels in motion. Some of this mechanical motion is changed back again into heat by friction among the various parts of the machine; and when an engine-driver applies the brake to stop his train the rails become warmer and sparks are seen to fly from the wheels. Electric currents can also perform work, and are therefore forms of energy. If a current of electricity is passing along a wire it will deflect a magnetic needle, and by passing around a bar of soft iron it will cause the bar to become a magnet, so that the iron will attract other pieces of iron near it. Chemical affinity is also a store of energy, for when different atoms unite to form a compound, heat, and sometimes light, is developed. Artificial heat is produced by combustion, and combustion is merely chemical union. The burning of coal is only the chemical union of the carbon and hydrogen of the coal with the oxygen of the air to form the two compounds carbonic acid and water vapour. A pound of carbon when burnt in oxygen to form carbonic acid gives out heat sufficient to raise about eighty-one pounds of water from the freezing to the boiling point, and this takes place whether the combustion be slow or quick. A store of gunpowder possesses potential energy due to chemical separation, and when it explodes by suddenly uniting with oxygen the energy becomes kinetic. The following table shows the different kinds of energy—kinetic visible energy and potential visible energy, kinetic molecular energy and potential molecular energy. This difficult subject will be better understood after reading the parts on Heat, Chemistry, and Electricity.

	Kinetic	Potential
Visible energy .	Due to the visible motion of a mass.	Due to a position of advantage, or to visible arrangements.
Molecular energy :		
Heat . .	Due to radiation and absorption.	Due to the heated state of a body.
Electricity .	Due to electricity in motion.	Due to electrical separation.
Chemical action	Due to actual chemical union.	Due to chemical arrangement.

42. **Conservation of Energy.**—The investigations of scientific men show that we can neither create energy nor destroy it, and that the sum of the kinetic energy and potential energy in the universe always remains the same. One kind of energy can be transmuted or changed into another. Visible motion, heat, electricity, and chemical affinity are all so many kinds of either kinetic or potential energy, and they are mutually convertible one into another. Examples of this 'transmutation of energies,' as it is called, have already been given. Moreover, a definite amount of heat corresponds to a definite amount of visible motion or of electricity, a

definite amount of chemical action to a definite amount of heat, and so on. Although the *form* of the energy may be changed, the *amount* always remains the same. These qualities of convertibility and indestructibility are often spoken of as the principle of the *conservation of energy.*

43. **The Sun the Great Source of Energy.**—The manifestations of energy due to the heat and light of the sun are very various. It is the sun's heat which warms the surface of the earth; and when this warmth is communicated to the overlying air it becomes rarefied and ascends, while fresh cool air flowing in from the sides takes its place. Thus the winds are caused which waft along some of our ships, and drive the sails of our windmills. It is also the heat of the sun which gives rise to the currents of the ocean, that so greatly affect the climate of certain countries. Again, by the heat of the sun some of the water on the surface of the earth is changed into vapour and carried up into the atmosphere. There it is condensed, and falls again on to the earth as rain and snow. This rain and snow collect as springs, rivers, and glaciers; and, as we shall shortly learn, these moving masses do an immense amount of work, and produce wonderful changes in the rocks of the earth's surface. With the single exception of the tides, which are produced mainly by the attraction of the moon, all the movements of water are due to the energy derived from the sun. But not even yet have we exhausted the effects of the sun's rays. The energy of man and other animals is derived from the food which is eaten; and if much work is done, more food is required than when little or no work is done. Work wears out the tissues of the body, and rest and food are required so that new tissue material may be formed. Our food is obtained from the vegetable world; for even if we eat beef or mutton, this has been prepared for us by the ox or sheep from the grass or turnips on which it fed. We must go a step further, and find out where the vegetable world got its store of energy from. Here the sun's rays come in as the active agent. Plants obtain the supply of carbon of which their tissues largely consist from the carbonic acid of the air. In the presence of sunlight the green parts of plants possess the power of withdrawing the carbon from the carbonic acid, and setting free the oxygen, and this carbon becomes fixed in the parts of the plant. The kinetic energy of the sun's rays is thus transformed into the potential energy of position, represented by the chemical separation of the oxygen and carbon of the carbonic acid.

Without the sun's rays there could be no vegetable world. The carbon of the vegetable tissue is thus ready to enter again into chemical combination with oxygen, and to come forth as the kinetic energy of muscular exertion; for this combination of oxygen with carbon and other elements is really what takes place in the various tissues of our body, and it is this slow combustion which furnishes our frames with the energy put forth. But all the vegetable matter of the world has not been consumed by animals. Much of it has lain buried for long ages deep down in the earth, and has there been transformed into coal. It is the combustion of this coal which produces the heat that forms the steam from which our locomotive and other steam engines derive their moving energy. So that in very truth the sun is the great source of energy on our globe.

CHAPTER IV.

HEAT

44. Of all the forms of energy about which we have been speaking, heat is one of the most important. When we come to understand its nature and the laws of its action we shall be able to explain many of the common appearances and occurrences that take place in the world. Daily experiences lead us to speak of some bodies as *hot* and of others as *cold*; but the term cold must only be understood to mean the comparative absence of heat, just as *dark* denotes the absence of light.

45. **Nature of Heat.**—For a long time it was thought that heat was an invisible weightless fluid entering and leaving bodies, so as to cause the sensations of warmth and cold. This fluid was called *caloric.* But it has been proved that heat is not a substance at all, for it can be produced in unlimited quantity by friction, and matter cannot be created out of nothing. Two pieces of ice can be melted by friction in a vacuum at freezing-point, and this could not be the case were heat a fluid as was once supposed.

According to the opinion now held, heat is considered to be nothing more than 'a mode of motion.' It consists in the oscillating motions of the molecules of a body, and it spreads itself to distant bodies by producing quivering motions in a medium which is believed to pervade all space, and which is called the *ether.* This ether is regarded as a highly elastic invisible substance, filling all space and permeating all matter, so as to occupy the space between the molecules of bodies. It has more of the properties of a solid like jelly than the properties of a gas. This ether takes up vibrating or oscillating motion from luminous and hot bodies, and transmits this motion through itself in the form of waves or undulations. These strike against certain parts of our bodies and cause the sensation of light or heat. No one has seen or felt this medium called ether, but it is believed to exist because it explains, as nothing else can, the various phenomena of light and heat. Heat, then, is molecular motion, and is the cause of those sensations we call warm and hot.

46. **Sources of Heat.**—The great source of heat is the sun. It is said that the total amount of heat received by the earth from the sun in one year would melt a layer of ice surrounding the earth 105 feet thick. But there are sources of heat on the earth itself, which may be called terrestrial sources. These are—

(1) Mechanical actions, such as friction, percussion, and the stoppage of a moving body.

(2) Chemical actions, such as combustion and other cases of chemical union.

(3) Electrical action, as when the passage of electricity is impeded. But even these, as we have shown, may be traced to the sun as their ultimate source.

47. **Relation between Heat and Work.**—The exact relation between mechanical work and heat has been determined by Dr. Joule. He showed not only that work can be converted into heat, but that the same amount of work always produces the same amount of heat. A weight of one pound raised to a height of 772 feet will generate on striking the earth sufficient heat to raise one pound of water one degree Fahrenheit; and, conversely, the amount of heat required to raise one pound of water one degree Fahrenheit might be made to lift one pound to a height of 772 feet. Hence 772 foot-pounds is called the mechanical equivalent of heat. (See Conservation of Energy.)

48. **Measurement of the Temperature (or Hotness) of a Body.**—The effect of heat is made use of to determine the temperature of a body. The word temperature signifies the amount of *sensible* heat in a body—that is, the amount of heat which can be made evident to the senses by means of some instrument. It is a quality of bodies, and hence we speak of *degrees* of temperature. More accurately the word has been thus defined and explained :—'The temperature of a body is its thermal condition with reference to its power of communicating heat to, or of receiving heat from, other bodies; the body A being said to have a higher temperature than B if B gain heat from A when they are placed in contact. Hence if, when two bodies are placed in contact, neither of them gains heat at the expense of the other, the two bodies are said to be at the same temperature' (Garnett). A body is said to have a high temperature when it is capable of communicating much heat to surrounding objects; and it is said to have a low temperature when it is capable of imparting little, or of receiving heat from them.

A thermometer is an instrument for measuring the temperature of bodies. Care must be taken not to confound the temperature of a substance with the *quantity* of heat it possesses. A glass of water may have the same temperature as a large boiler, but the amount of heat possessed by the two is very different. The instrument that measures the amount of heat in a given amount of a substance is called a *calorimeter*.

49. **Construction and Graduation of a Thermometer.**—Nearly all bodies expand or increase in volume when they are heated, and contract or diminish in volume on cooling. This effect is made use of in measuring temperature, and the most convenient substance is a fluid having its free surface in a narrow tube of small bore. A small increase of volume consequent on an increase of temperature can thus be easily observed.

The fluids most frequently employed are mercury, alcohol, and air. In order to construct a mercurial thermometer a glass tube with a very fine bore is taken, having a bulb blown at one end. At first the upper end of the tube is open, and in order to get the mercury to enter the tube a little cup is attached to this end, and mercury poured into this cup. The bulb is now gently heated, and a portion of the air is thus driven out, bubbling through the mercury in the cup. As the bulb cools, and the air in the tube contracts, mercury is forced by the pressure of the atmosphere through the tube into the bulb. This mercury in the bulb is then heated until it boils. The remaining portion of air is thus expelled, and the tube becomes filled with heavy vapour of mercury. On cooling this vapour condenses, and more mercury now enters, so as to fill the bulb and tube completely.

The bulb and tube are again heated to a point a little beyond the highest temperature it is intended to measure, and while still hot the top of the tube is sealed by the blowpipe. As the mercury cools in the sealed tube it contracts, and leaves a vacuum at the upper end of the tube, while the bulb and a portion of the stem are occupied by the liquid. The thermometer now requires to be graduated, *i.e.* marked with degrees or regular intervals. In order to do this it is first placed on melting ice or melting snow, and a mark made on the tube at the point to which the mercury has contracted. This is called the *freezing-point.*

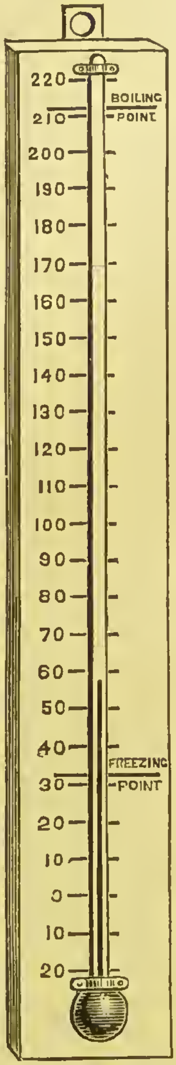


Fig. 9.—Fahrenheit's Thermometer.

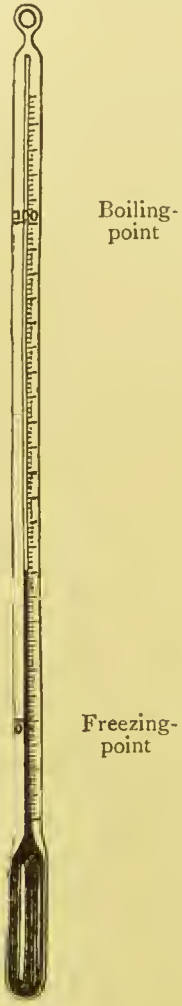


Fig. 10.—Centigrade Thermometer.

After the freezing-point has been determined, the instrument is placed in the vapour of water boiling at the normal or standard pressure of the atmosphere. The mercury rises, and a second mark is made on the tube at the end of the mercury column. This is called the *boiling-point.* The space between these two marks is then divided into any number of equal parts that may be chosen, and parts of equal length are also marked off some distance below the freezing-point and some distance above the boiling-point. These equal divisions are called degrees, and this division of the thermometer into equal parts is called the *graduation* of the thermometer (Lat. *gradus,* a step or degree). In the Centigrade thermometer the space between the two fixed points is divided into 100 equal parts, 0 being placed at the freezing-point and 100 at the boiling-point.

In Fahrenheit's thermometer the space between freezing-point and boiling-point is divided into 180 equal parts, 32 being put at freezing-point and 212 at boiling-point. Hence in this thermometer the zero is 32 degrees below freezing-point. This is the thermometer in common use in this country.

In both thermometers temperatures below the 0 are distinguished by having the *minus* sign prefixed. Thus $-6°$ C. denotes 6 degrees below freezing-point on the Centigrade thermometer, and $-6°$ F. denotes $32+6=38$ degrees below the freezing-point of Fahrenheit's thermometer.

Since 100 divisions or degrees on the Centigrade are equal to 180 degrees on the Fahrenheit, we see that 5 degrees C. = 9 degrees F. Hence it is easy to see how to pass from one thermometer to the other. From C.

to F. multiply the number of degrees on the Centigrade scale by 9, divide by 5, and add 32. $F. = \frac{9}{5} C. + 32$. From F. to C. subtract 32, multiply by 5, and divide by 9. $C = \frac{5}{9} (F. - 32)$.

50. Reasons for employing Mercury for Ordinary Thermometers.

(1) It is a liquid that can easily be obtained in a state of purity.

(2) It remains liquid through a great range of temperature, viz. −40° C. to 350° C., or −40° F. to 662° F.

(3) It quickly transmits heat through its substance, so that it soon acquires the temperature of the body with which it is in contact.

(4) It requires but little heat to raise its own temperature, so that it affects but slightly the temperature of the substance in which it is placed.

(5) It does not wet the glass envelope in which it is put.

Alcohol thermometers are used for measuring very low temperatures, and also for what are called *minimum* thermometers. Alcohol is a liquid that has never been frozen at any degree of cold to which the earth is subjected.

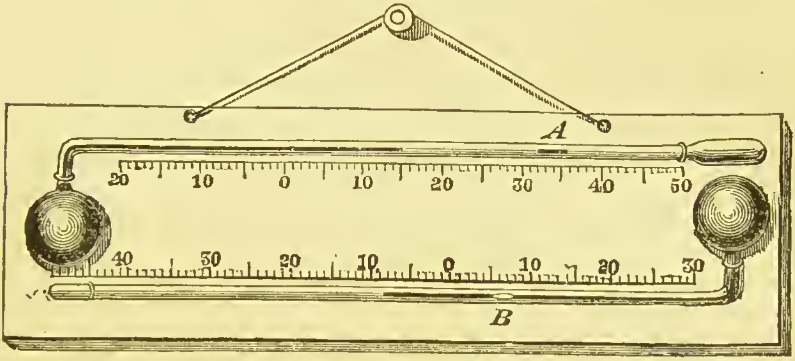


FIG. 11.—Maximum and Minimum Thermometers fixed horizontally on a rectangular piece of wood. *A*, maximum thermometer, containing mercury with the index registering 32° C. as the highest temperature attained. *B*, minimum thermometer, containing alcohol with the index registering 5° C. below zero as the lowest temperature reached.

Air thermometers are used to measure very slight variations of temperature, as gases expand more than liquids, and also for very high temperatures.

51. Maximum and Minimum Thermometers.—The *maximum* thermometer is an instrument used for indicating the highest temperature to which it has been exposed since it was adjusted. Rutherford's maximum self-registering thermometer consists of an ordinary mercurial thermometer placed in a horizontal position, and having a small piece of steel inside the tube *beyond* the mercury.

As the mercury expands with increase of temperature it pushes the steel before it, and as it contracts it leaves the steel in the furthest position to which it has been driven. The end of the steel nearest the surface of the mercury marks the highest temperature since it was last set. The instrument can be prepared for another observation on bringing back the steel into contact with the mercury by means of a magnet.

The *minimum* thermometer is used to indicate the lowest temperature reached since the last observation. It contains alcohol instead of mercury, and *inside* the alcohol contained in the tubes there is a small index of glass, with the furthest end touching the surface of the alcohol. This tube is also placed horizontally. As the alcohol contracts it carries the index of glass with it, but when it expands the index is left behind. Thus the end of the index nearest the surface of the spirit shows the lowest temperature. The index can be again got into position by inclining the tube.

52. **Uses of the Thermometer—Methods of using Thermometers.**—We have seen that a thermometer is used for measuring the temperature or degrees of heat of substances brought into contact with it, but in order to do this accurately certain precautions must be observed. We must take care that the thermometer is only affected by the body whose temperature we wish to ascertain, and that it is neither receiving heat from nor giving up heat to other bodies. We must also allow the thermometer to be sufficiently long in contact with the body to acquire the same temperature. Thus, to ascertain the temperature of a liquid we must allow the bulb and part of the stem to remain in the liquid for a short time. The temperature of the human body may be ascertained by placing a small thermometer in the mouth till it has come into thermal equilibrium with it.

One of the most important uses of the thermometer is to ascertain the temperature of the atmosphere. To do this is a somewhat difficult matter. If we allow the sun to shine upon it the reading will be too high. Hence, to find out the temperature of the air the thermometer must be in the shade. Here, however, it must not be affected by bodies colder than the air, or the reading will be too low. The air must also have free access to the instrument on all sides. To meet these difficulties a maximum and minimum thermometer are often placed inside a rectangular screen made of wood louvred on all sides except the top, and placed on legs in an open space so that the instruments are about four feet from the ground. They are thus protected from radiation either from the sun or from surrounding objects, and their readings show the highest and lowest temperatures since last set.

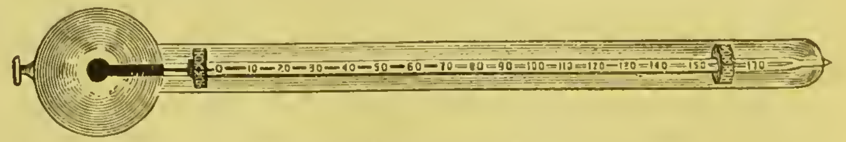


FIG. 11*a*.—Solar Radiation (Black Bulb) Thermometer.

53. **Black Bulb Thermometer in Vacuo.**—This is a thermometer constructed, not for the purpose of measuring the temperature of the air, but for measuring the intensity of solar radiation, or the amount of the sun's heat that reaches the layer of the atmosphere where it is placed. It would

not suffice to expose an ordinary thermometer to the sun's rays for this purpose, for the bright bulb would reflect and radiate back some of the heat that fell upon it. But when the bulb and part of the stem are coated with lamp-black (a variety of carbon) the whole of the sun's rays are absorbed. To prevent loss of heat from this bulb by air currents and radiation it is enclosed in a clear glass tube with a bulb blown at the end, and this outer tube and bulb are exhausted of air. The black bulb thermometer thus consists of a good maximum thermometer, having the bulb and about an inch of the stem coated with dull lamp-black and enclosed in an exhausted glass tube. It is placed about four feet from the ground and freely exposed to the sun's rays.

The ordinary rule for using the instrument is to notice the maximum temperature indicated during the day, and to compare this with the maximum temperature indicated by the shade thermometer. The *difference* of the two thermometers indicates the greatest amount of solar radiation during that day.

54. **Expansion.**—It has already been remarked that one general effect of heat is to cause bodies to expand or increase in bulk (size in all directions). Solids expand least, liquids expand more than solids, and gases expand most.

55. **Expansion of Solids.**—To show the expansion of solids we may take a bar which when cold just fits into a groove, and then heat it. It will then be found to fit no longer. It is because of this expansion that the ends of the rails on a railway are placed at a small distance apart, else the summer's heat would bring them so tightly in contact as to twist them. As the heated body cools contraction takes place. If a ball of metal *a* be made of such a size as to exactly fit a ring *m* when the two are at the ordinary temperature of the air, it will be found on heating the ball that it no longer passes through the ring. On cooling, however, to its original temperature the ball again passes through the ring. The shrinking effect of cooling is made use of by the wheelwright when he puts on the iron tire of a wheel while red-hot, and then cools it by throwing on water. The contraction consequent on the iron becoming cold binds the parts firmly together.

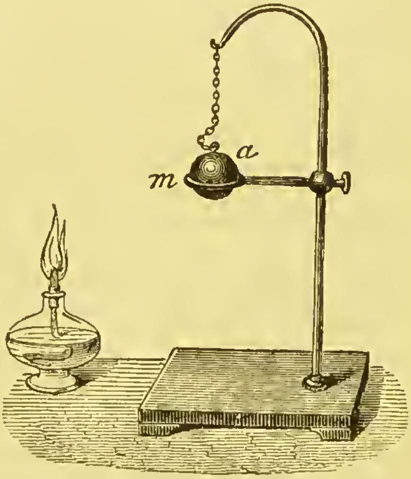


Fig. 12.—Showing Expansion of Metal Ball by Heat.

Different solids expand differently for the same increase of temperature. Thus zinc expands more than silver, silver more than iron, and iron more than copper or glass.

56. **Expansion of Liquids.**—On taking a flask full to the brim with water and heating it, the water will soon begin to flow over, owing to its expansion. If we take the thermometer from the wall of a room and place it in hot water, the liquid mercury is seen to rise. Remove the thermo-

meter and the mercury falls, owing to its contraction on cooling. As we saw in describing the thermometer, it is the expansion and contraction of the mercury which furnishes us with the means of measuring the temperature of bodies in contact with it. Different liquids undergo different amounts of expansion for equal increments of temperature, but the case of water presents certain peculiarities so important that it needs special attention.

57. *Exceptional Case of Water.*—At certain temperatures water obeys the general rule, expanding for an increase of temperature and contracting for a diminution of temperature, but at certain other points there are important deviations from this rule.

As before remarked, if we take a vessel of water and heat it, the water begins to expand until it reaches its boiling-point. It then passes off as vapour, increasing in volume about 1,700 times. But, before it is all evaporated, take some of the hot water, and let it cool slowly, and we shall be able to notice that it contracts until it comes near the freezing-point, 39° F. (4° C.), when it begins to *expand*, and continues to do so until the freezing-point is reached, 32° F. (0° C.). Just as it becomes solid it again enlarges, so that ice is lighter than water bulk for bulk.

The specific gravity of ice is ·92, water being 1. Hence it is that ice forms on the surface and will float.

Water has, therefore, its greatest density and least bulk at 39° F. (4°C.). At 32° F. (0° C.) it freezes. Hence between the temperatures of 39° F. and 32° F. (4° C. and 0° C.) water behaves in an exceptional manner, expanding as the temperature falls from 39° F. to 32° F., and contracting as the temperature rises from 32° F. to 39° F. This exceptional behaviour of water between 39° F. and 32° F. is of great importance in the economy of nature. If water did not expand as the temperature gets near the freezing-point and at the moment of freezing, the whole of the water in a river or lake would increase in density and sink from the surface to the bottom till the whole reached 32° F. It would then become solid throughout, and instead of having the ice form on the top as it does, the whole mass would become frozen.

Probably the reason why ice expands at the moment of freezing is that the arrangement of the crystals in ice (for ice has a crystalline structure) takes up more room than when the water is in the liquid state.

We will now summarise these facts in a tabular way :—

(1) Ice expands from below freezing-point to 32° F. like other solids.
(2) At 32° F. ice melts, and there is contraction of bulk.
(3) From 32° to 39° F. the water still further contracts.
(4) At 39° F. the water has its maximum density or least bulk.
(5) From 39° F. to 212° F. the water expands.
(6) At 212° F. the water boils and undergoes enormous expansion.
(7) Water vapour expands regularly on being further heated.

The pupil may write out the above table, using Centigrade degrees instead of those of Fahrenheit.

We are now able to understand clearly what takes place when a pond or other sheet of water freezes. The water at the surface is first chilled by the cold air, and this becoming heavier than the water below, sinks, whilst the lighter, warmer water rises to supply its place. This goes on till the temperature of the whole mass is reduced to 39° F. (4° C.), after which the surface water no longer sinks, for on being cooled below 39° F. the water expands, and, being lighter than the deeper water, remains at the top. This colder water at the surface being then reduced to the freezing-point is turned into solid ice floating on the water below, and serves to some extent as a protection from the cold at the surface. The ice formed then slowly increases in thickness in proportion to the intensity of the cold at the surface.

The great force with which water expands on freezing can be shown by the following experiment :—

An iron bomb-shell or bottle is filled quite full with water, and then firmly closed with an iron screw. The shell or bottle is then exposed to frost, and after a time it is heard to burst with a loud noise, and a quantity of ice is forced through the crack as is shown in the figure.

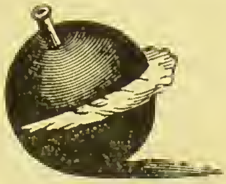


FIG. 13. — Iron Shell broken by Freezing Water.

Ice possesses a peculiar property called *regelation*. When two fragments of ice near the melting-point are pressed together, they at once freeze into one mass, but if the pieces be some degrees below freezing-point this does not take place. Boys often squeeze the icy particles of which snow consists into a ball, but when the snow is very cold no snowball can be formed. This phenomenon of regelation was first examined by Faraday ; its explanation is still under discussion.

58. **Ground Ice.**—Ice called 'ground ice,' or 'anchor ice,' sometimes forms at the bottom of quickly moving rivers, while the rest of the water remains unfrozen.

Owing to the movement among the particles of water the temperature of the water may be reduced several degrees below freezing-point before ice is formed. The action of the running stream mixes the cold surface water with the water below, and then ice is formed at the bottom owing to the greater stillness of the water there, and because the sharp points of the rock and shingle present surfaces which induce the water to crystallise or freeze. Ice is thus formed in the bed of a river, clinging to the pebbles and weeds, and when the temperature rises after sunrise its buoyancy causes it to rise to the surface, lifting up and floating away the loose stones and other substances to which it is attached.

59. **Expansion and Contraction of Gases.**—If we take a bladder about half full of air, carefully tie it up, and then warm it before the fire, we shall soon find that it swells out and becomes smooth and round, through the expansion of the air inside. On cooling, it again shrinks.

The expansion of gases is subject to a much simpler law than the expansion of solids and liquids ; for while different solids and liquids have different rates of expansion, all gases expand equally for the same increase of temperature. The law is—'Gases expand $\frac{1}{273}$ of their volume for every increase of 1° C. starting from zero.' This is sometimes called the law of Gay Lussac, or the law of Charles.

The expansion and contraction of air as the temperature rises or falls serves to explain many familiar phenomena. The *draught* in a chimney is caused by a current of heated air and gas which, being lighter bulk for bulk than the cold air, ascends, other air passing in from the room to maintain the combustion and the upward current.

The *ventilation* of rooms is best brought about by letting the hotter and lighter air escape near the ceiling while the cooler fresh air is admitted below.

When a candle is held near the top of the open doorway of a room in which a fire is burning the flame is carried outwards, but if it be held at the bottom the flame is carried inwards by the colder air coming in from the outside.

Winds are produced by difference of temperature, the warm rarefied air near the surface ascending, and colder air coming in to supply its place.

60. **Latent Heat.**—We have seen that matter exists in three forms or states—solid, liquid, and gaseous (art. 29); that in solids the particles are held together by a force of molecular attraction called cohesion; that in a liquid this force is much less, the molecules being free to move over one another in any direction; while in a gas the force of cohesion has no existence at all, as the particles repel each other and tend to fly off in all directions. It is by the application of heat that solids are turned into liquids, and liquids into gases. By the withdrawal of heat gases are turned into liquids, and liquids into solids. Carbon, however, is a solid which has never yet been turned into either a liquid or a gas, and alcohol is a liquid that has not been frozen.

Let us consider more carefully what takes place when these changes of state occur. If we take a quantity of ice and apply heat, it begins to melt. But while the process of melting goes on the temperature does not rise, for until all the ice is melted the temperature remains at freezing point. What, then, becomes of the heat? It is expended in liquefying the ice; that is, in lessening the force of cohesion, or doing interior *work*. The heat thus sensibly lost and expended in changing the state of the body is called *latent heat*.

We may further illustrate the matter in this way. If we take a pound of water at 0° C. and another pound at 79° C., and mix the two, we shall find the mixture to be at a temperature halfway between the two, viz. 39·5°. But if we take a pound of ice at 0° C. and mix it with a pound of water at 79° C., we shall find that the ice will be melted, but that the temperature of the whole mass of water is only at freezing-point, 0° C. The heat of the pound of water has been used up in melting the pound of ice. Other solids in fusing absorb heat, which becomes latent, but the latent heat of water is greater than that of any other body. In the opposite process of solidification a quantity of heat is given up again. Hence the large amount of heat latent in water is again given up as it freezes, and this serves to lessen the severity of a frost, as it renders the freezing of masses of water a much more gradual process than it would otherwise be. In the slow liquefaction of ice, too, we see how it is that a thaw does not produce a sudden deluge of water.

61. **Evaporation and Ebullition.**—When a liquid passes into the gaseous state, it is found that there is even a greater disappearance of heat than there is when a solid is changed into a liquid. If water be placed in an open vessel and heat applied, a thermometer would show that the temperature gradually rises until it reaches 100° C. (212° F.). The water then passes off rapidly as a vapour, and the temperature of the water

in the vessel remains at 100° C. (212° F.). By continuing the heat for some time all the water may be driven off as steam, and the fact that the temperature remains stationary at 100° C. (212° F.) shows us that the heat is being used up in turning the water from a liquid into a gas, and in overcoming the pressure of the atmosphere.

The amount of heat thus rendered *latent* is 536 thermal units, a thermal unit being the amount of heat required to raise the temperature of a pound of water 1° C. from 0° C.

The number 212° F. or 100° C. only expresses the boiling-point of water at the ordinary pressure of the atmosphere. If the pressure diminish the boiling-point is lowered, because the elastic force of the vapour generated in the liquid is sooner able to overcome the atmospheric pressure at the surface. Hence as we ascend a mountain the boiling-point gradually diminishes, the rate of diminution being about 1° C. for every 1,000 feet. In this way observation of the boiling-point may be used to find out roughly the height of a mountain.

Some liquids boil at a lower temperature than water, and some at a higher. This is because the elasticity of their vapour, or the tension of the vapour, as it is called, differs from that of water. But in all cases the same liquid boils at the same temperature if the pressure be the same ; and the tension of its vapour always equals the pressure of the atmosphere at the place. It should be noted that water slowly evaporates at all temperatures, giving off invisible vapour from its surface, which diffuses into the surrounding air. In boiling or ebullition the bubbles of vapour are formed *within* the liquid.

62. **Condensation.**—When the water vapour suspended in the atmosphere is condensed, the latent heat of the vapour is again given back to the atmosphere. In this way our south-westerly winds, laden with moisture from the warm tropical regions of the earth, on reaching a cooler district have their moisture condensed, and give up a certain amount of heat.

The molecules of water, in fact, when separated by heat, possess potential energy, or energy of position, and this is changed again into sensible heat as the vapour cools and condenses.

It must be remembered that real steam is invisible, as may be learnt by boiling water in a vessel with a glass spout. No steam will be seen in the spout until it has come out a small distance. The cloud we usually call steam arises from the condensation of the steam into minute watery particles by the colder atmosphere. Water, in passing into the gaseous state, undergoes an enormous increase in volume, 1 cubic inch of water becoming about 1,700 cubic inches of steam. There is a corresponding diminution of volume when the steam condenses again into water.

63. **Specific Heat.**—All substances do not require the same quantity of heat to raise them to the same temperature. If one pound of water and one pound of mercury, both at the same temperature, be subjected for the same length of time to the same heat, it will be found that when the water has increased in temperature one degree the mercury has risen thirty degrees. This is expressed by saying that water has a great *specific capacity* for heat. It requires thirty times as much heat to pass into water as is

required to pass into mercury, in order to produce the same rise in temperature. The amount of heat taken up by a given weight of a body in order to increase its temperature a given number of degrees is just the same as the body gives off as its temperature sinks through the same number of degrees. Although, therefore, water has such a great capacity for heat, it must be noticed that, in cooling, it gives off the large quantity it required to become warm.

Definition :—The specific heat of a substance is the quantity of heat required to raise that substance through one degree of temperature, compared with the quantity of heat required to raise an equal weight of water from 0° C. to 1° C. Water, having the greatest specific heat, is taken as the unit.

Here is the specific heat of a few important substances :—

Water . . .	1·00	Mercury . . .	·033
Silver . . .	·056	Alcohol . . .	·674
Charcoal . . .	·242	Oxygen . . .	·218
Iron	·114	Nitrogen . . .	·244

64. **Important Effects of the Great Specific Heat of Water.**—Since water requires such a large quantity of heat to raise its temperature, and since it gives out the same quantity in cooling, it is easy to see that large bodies of water will exert considerable influence on the climate of a country. During the hot parts of the year the water absorbs a considerable quantity of heat without any great alteration of its temperature. In the cold parts of the year, as the waters of the sea become cooler, a considerable quantity of heat is given up to the land and the air with which it is in contact. Thus maritime countries have the extremes of temperature greatly modified by the influence of the ocean waters.

65. **Propagation of Heat.**—Heat is transferred from one piece of matter to another in three different ways—by radiation, convection, and conduction.

66. *Radiation.*—The process by which heat is transmitted across a space from one body to another is called radiation. When we stand in front of a fire, or in the bright sunshine, the warmth we feel is caused chiefly by radiation. The rays of heat from the fire or the sun pass through dry air without heating it, just as rays of light pass through transparent bodies. These rays of heat are not warm of themselves, and they do not raise the temperature of the bodies through which they pass. It is only when they fall upon a body and are absorbed by it that their heating effect is produced. The great supply of heat received by the earth from the sun is transmitted by the process of radiation. These rays proceed like rays of light in all directions and in straight lines. Every hot body sends forth heat in all directions, whether the body be luminous like a jet of gas, or non-luminous like a vessel of hot water. There are thus two kinds of heat rays—*luminous heat rays*, in which rays of heat are combined with rays of light ; and *obscure* or *dark heat rays*, where light is absent.

When rays of heat strike against any body, a portion of the heat is *absorbed*, so as to produce heat within the body, while another portion is *reflected*, or thrown back from the surface. But some substances *transmit* or allow the greater portion of the heat to pass through them. They are then said to be *diathermanous*. Those bodies which are good absorbents of heat also radiate heat well, and those which are bad absorbents are bad radiators. Only those rays that are absorbed serve to warm the body, those that are reflected or transmitted having no effect on the temperature. Lamp-black is a substance remarkable for its power of absorption, for it transmits none of the radiant heat which falls on it, and reflects very little. Polished metals are good reflectors, absorbing very little and transmitting none. Rock-salt transmits radiant heat very well; it hardly absorbs any, and reflects but little. It should be noticed that some substances, like glass and water, allow the luminous rays to pass through but absorb the dark heat rays.

Professor Tyndall has shown that dry air has scarcely any power to absorb rays of heat, but that the aqueous vapour which is always present more or less in the atmosphere absorbs a very large amount of the rays of dark heat, though it allows the sun's rays to reach the earth with only slight loss. 'The result is that we have nearly the full effect of the sun's rays in heating the earth; but once the earth has been heated, this terrestrial heat cannot easily pass out through the aqueous vapour of the atmosphere into empty space; but as it consists of dark rays it is stopped thereby. Thus the aqueous vapour acts as a trap in allowing the sun's rays to pass in and heat the earth, while it prevents the heat of the earth from passing outwards into space. The earth's surface is by this means kept much hotter than it would otherwise be.' (Balfour Stewart's 'Lessons in Elementary Physics.')

67. *Conduction.*—Conduction of heat is the transference of heat through the mass of a body from particle to particle. If we place a rod of iron and a piece of wood of the same length in the fire, we shall soon find that the iron becomes hot at the opposite end, owing to the conduction of heat from molecule to molecule along the rod, while the wood can be held in the hand as it burns away. Bodies which readily propagate heat through their mass are said to be good conductors, and those through which heat passes slowly and with difficulty are called bad conductors. Most of the metals are good conductors of heat, silver and copper being the two best. Cotton, wool, feathers, straw, and other organic substances are very poor conductors. They thus prevent the escape of heat generated in the bodies of animals. Our clothes, therefore, do not make us warm, but only keep us warm by their not conducting the heat outwards, and by preventing the cold air from carrying off the bodily heat. Ice can be preserved from melting on a warm day by wrapping it in blankets, as the blankets do not readily carry the heat of the air inwards to the ice. Thus a bad conductor may not only keep heat in, but also keep it out.

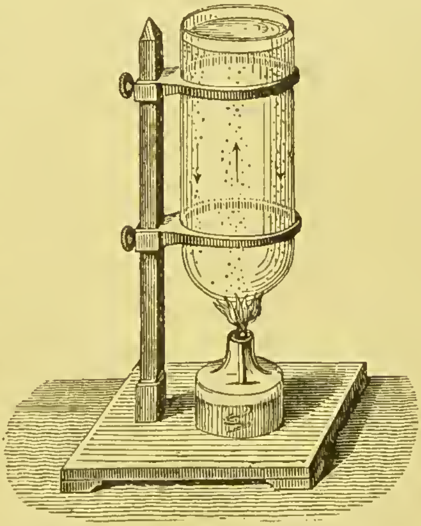


FIG. 14.—Convection Currents formed during the Heating of Water.

Nearly all liquids and gases are bad conductors of heat, and hence heat is not transmitted through them in the same way as in solids. If a test-tube of water be heated at the top it may be made to boil there while the liquid at the bottom remains comparatively cold. This shows that the water is a bad conductor of heat.

68. *Convection.*—If, however, the water be heated at the bottom, it soon becomes warmer throughout. This is not due to conduction, but the particles of liquid near the lamp or fire become heated, expand, and rise to the top. Colder particles descend to take their place, and these in their turn get heated and rise. In this way ascending and descending currents are formed, and the heat is spread through the whole mass. By introducing small pieces of blue litmus these currents can be rendered visible. This mode of heating is called *convection* (Lat. *conveho*, to carry up). The air is heated in this way by contact with the warm earth, and the heated air becoming specifically lighter ascends, and these convection currents are the cause of winds.

CHAPTER V.

CHEMICAL ACTION.

69. **Elements and Compounds.**—Chemistry is the science which treats of the composition of bodies, *i.e.* of the different kinds of substances of which the various pieces of matter are made up. Although the substances found on the earth are so numerous and varied, yet, as we have seen (par. 25), the chemist divides them into two classes only, elements and compounds. Everything we meet is either an element or a compound, or a mechanical mixture of these. *An element is a simple substance, consisting of only one kind of matter.* It cannot be split up or decomposed into different substances, nor can it be built up out of different substances. Thus *carbon* (of which pure charcoal is a variety) is an element, because nothing but carbon can be obtained from it. It is indecomposable. For the same reason the gas called oxygen and the liquid metal mercury are elements. But carbon can be made to unite with oxygen by the force of chemical affinity, and a compound called carbonic acid or carbon dioxide is then produced. This union is brought about whenever carbon burns ; for this burning results from the carbon uniting with the oxygen of the air and forming the invisible gas called carbonic acid gas. Hence carbonic acid is a compound substance, for it consists of two kinds of substances, oxygen and carbon, chemically united. Water is a compound formed by the union of two gases, oxygen and hydrogen. Limestone is a compound also, and contains three elements, calcium, carbon, and oxygen, united together. A *compound*, then, is *a substance formed of two or more elements united together by*

the force of chemical affinity. There are only 65 elements known, but there are many thousands of compounds. *Binary* compounds are compounds formed by the union of *two* elements. Thus carbonic acid and water are binary compounds. *Ternary* compounds are compounds formed by the union of *three* elements, as limestone. Many other examples of both these classes will presently occur. Some compounds contain more than three elements. As already stated, the power which causes the various elements to unite with one another in order to form compounds, and which holds them together after they have united, is called chemical attraction or chemical affinity.

70. **Chemical Symbols and Formulæ.**—Instead of writing the full name of each element and compound, the chemist uses a kind of shorthand. Each element has a sign or *symbol*, and this symbol is the first letter (or sometimes the first letter and another) of its English or Latin name. But it is important to notice that this symbol not only stands for the element, but also for a definite quantity by weight of that element. Thus H not only stands for hydrogen, but also for one atom of hydrogen. As hydrogen is the lightest substance known, its atom is taken as the unit, and to it the number 1 is attached. O stands for oxygen, and for one atom of oxygen; and, as oxygen is sixteen times heavier than hydrogen, the number 16 is attached to the symbol O. In the same way C stands for carbon, and for 12 parts by weight of carbon. The symbol Ca is used for the element calcium, the weight of which compared with hydrogen is 40. These numbers are called the *atomic* or *combining weights* of the elements, and they represent the relative weights of the elements when hydrogen is taken as the unit. Compound bodies are represented by placing the symbols of the elements composing them side by side. Thus the compound called mercuric oxide consists of one atom of mercury (Hg) united with one atom of oxygen (O), and it is therefore represented thus, HgO. Carbonic acid is formed by the union of one atom of carbon and two atoms of oxygen; hence it is represented by CO_2, the small figure at the right of an element indicating the number of atoms of that element. HgO and CO_2 are called the chemical *formulæ* of mercuric oxide and carbonic acid respectively. A chemical formula, therefore, is the representation of a chemical compound by means of symbols. H_2SO_4 is the chemical formula of sulphuric acid (also called oil of vitriol), and this formula teaches us that it consists of two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen, chemically united. The quantity of any compound which is represented by its formula is spoken of as a molecule. Thus H_2SO_4 represents a molecule of sulphuric acid, and $2H_2SO_4$ represents two molecules. A molecule of an element usually contains two atoms; H_2 represents a molecule of hydrogen (see definitions of atom and molecule in par. 27).

By means of this shorthand we can also express chemical changes shortly and exactly whenever a chemical action takes place. Chemical actions always produce changes of composition. The sign + placed between two formulæ shows that the two bodies represented have been added together. The sign = is usually employed in the sense of the word 'yields' or 'produces.' Thus when carbon is made to burn in oxygen, the two substances unite and carbon dioxide is produced. This chemical action is shortly expressed by the following equation :

$$C + O_2 = CO_2.$$

When zinc is placed in dilute sulphuric acid, H_2SO_4, the zinc displaces the hydrogen of the sulphuric acid and sets it free. Expressed in chemical signs, this change is written thus :

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

Such changes as these are often spoken of as *reactions*, and chemical reactions are usually represented by equations.

71. **Number and Classification of the Elements.**—*Tables of Elements.*—The total number of elements at present known is about 70, but many of these are rare and seldom met with. Most of the elements are solids at the ordinary temperature of the air, but bromine and mercury are liquids; and oxygen, hydrogen, nitrogen, and chlorine are gases. The elements are divided into two classes, *metallic* and *non-metallic*. The metals are distinguished from the non-metals by their lustre, malleability, metallic ring when struck, and by generally possessing a high specific gravity and being good conductors of heat and electricity. The following tables supply lists of (1) all the non-metals, (2) all the common metals, with their symbols and atomic weights. Where the Latin name differs from the English it is added in brackets. The fourth column supplies examples of one or two of the many important compounds of these elements, with the formula of each compound. It should be noticed that some of these compounds have more than one name.

Fire, Earth, Air, and Water not Elements.—Some of the ancients used to speak of fire, earth, air, and water as elements, but we can now understand why the chemist does not regard them as elements. Fire is only a state or condition of matter ; the solid earth is made up of numerous substances, most of which are compounds; air consists of a mechanical mixture of gases, chiefly nitrogen and oxygen, without any chemical union between them ; and water is a compound formed by the chemical union of the two gases oxygen and hydrogen.

I. *Non-metallic Elements.*

Names of Elements	Symbols	Atomic Weights	Compounds (chiefly Binary)
Boron . . .	B	11	B_2O_3, boron trioxide or boric anhydride
Bromine . .	Br	80	HBr, hydrobromic acid
Carbon . . .	C	12	CO_2, carbonic acid or carbon dioxide ; $CaCO_3$, calcium carbonate
Chlorine . .	Cl	35·5	HCl, hydrochloric acid
Fluorine . .	F	19·1	HF, hydrofluoric acid ; CaF_2, calcium fluoride or fluor-spar
Hydrogen . .	H	1	H_2O, water ; CH_4, marsh gas
Iodine . .	I	126·5	HI, hydriodic acid
Nitrogen . .	N	14	NH_3, ammonia; HNO_3, nitric acid

I. *Non-metallic Elements*—continued.

Names of Elements	Symbols	Atomic Weights	Compounds (chiefly Binary)
Oxygen . . .	O	16	H_2O, water ; PbO, lead oxide
Phosphorus . .	P	31	P_2O_5, phosphoric pentoxide
Selenium . .	Se	78	SeO_2, selenious anhydride
Silicon . . .	Si	28	SiO_2, silica or silicon dioxide
Sulphur. . .	S	32	H_2S, sulphuretted hydrogen ; H_2SO_4, sulphuric acid

II. *Common Metals.*

Names of Elements	Symbols	Atomic Weights	Compounds (chiefly Binary)
Aluminium . .	Al	27·3	Al_2O_3, alumina or aluminium oxide
Antimony (Stibium)	Sb	122	$SbCl_3$, antimony trichloride
Arsenic . . .	As	75	As_2O_3, white arsenic or arsenic trioxide
Barium . . .	Ba	137	BaO, baryta ; $BaSO_4$, barium sulphate or Heavy Spar
Bismuth . .	Bi	210	$BiCl_3$, bismuth chloride
Calcium . .	Ca	40	CaO, lime or calcic oxide ; $CaSO_4$, calcium sulphate
Cadmium . .	Cd	112	CdO, cadmium oxide
Chromium . .	Cr	52·4	Cr_2O_3, chromium trioxide
Cobalt . . .	Co	59	$CoCl_2$, cobalt chloride
Copper (Cuprum) .	Cu	63·5	CuO, black oxide of copper
Gold (Aurum) .	Au	196·2	$AuCl_3$, gold chloride
Iron (Ferrum) .	Fe	56	Fe_2O_3, red oxide of iron
Lead (Plumbum) .	Pb	207	PbO, litharge or lead oxide
Magnesium . .	Mg	24	MgO, magnesia
Manganese . .	Mn	55	MnO_2, black oxide of manganese
Mercury (Hydrargyrum)	Hg	200	HgO, mercuric oxide
Nickel . . .	Ni	59	NiO, nickel oxide
Platinum . .	Pt	197	$PtCl_4$, platinum chloride
Potassium (Kalium)	K	39·1	K_2O, potash ; KHO, caustic potash
Silver (Argentum) .	Ag	108	AgCl, silver chloride
Sodium (Natrium) .	Na	23	Na_2O, soda ; NaHO, caustic soda ; NaCl, salt
Strontium . .	Sr	87·5	SrO, strontia or strontium oxide
Tin (Stannum) .	Sn	118	SnO_2, tinstone or oxide of tin
Zinc . . .	Zn	65	ZnO, zinc oxide ; $ZnCl_2$, zinc chloride

72. **Preparation and Properties of Oxygen.**—Oxygen gas exists in a free state in the atmosphere, but it is there largely mixed with another gas called nitrogen, the nitrogen forming about four-fifths and the oxygen one-fifth of the air. Pure oxygen can be most conveniently prepared from a

substance called potassium chlorate. To do this we take a quantity of this substance, powder it in a mortar, and then dry it well, so as to drive off any moisture it may contain. We then mix it with about one-third its weight of black oxide of manganese, as this substance enables us to decompose the potassium chlorate at a less heat than would be otherwise required. The potassium chlorate thus prepared is then placed in a flask or retort of hard glass which is fixed on a stand. Through a hole in the cork of the flask a glass tube is passed, and this tube is bent so that it dips into the water contained in a vessel called a pneumatic trough. In the pneumatic trough is placed a beehive-shaped shelf, having a hole in the side of the shelf for the bent delivery tube to pass into, and a hole at the top of the shelf for the gas to rise through. A glass bottle or jar is now filled with water and placed on the beehive shelf, so that its mouth still remains under water. The apparatus is now ready. The flask is gently heated, and after the air has been driven out the bubbles of gas that come off are allowed to pass up into the bottle and displace the water. When the bottle is full of the gas it is gently lifted oft the shelf, its mouth being still kept under water, and a ground-glass plate or a small tray is placed over the mouth. It can then be removed from the trough, and we have a bottle of pure oxygen gas. Two or three more bottles may be collected in the same way. The oxygen is obtained from the potassium chlorate, which is decomposed by heat into potassium chloride and oxygen, thus :

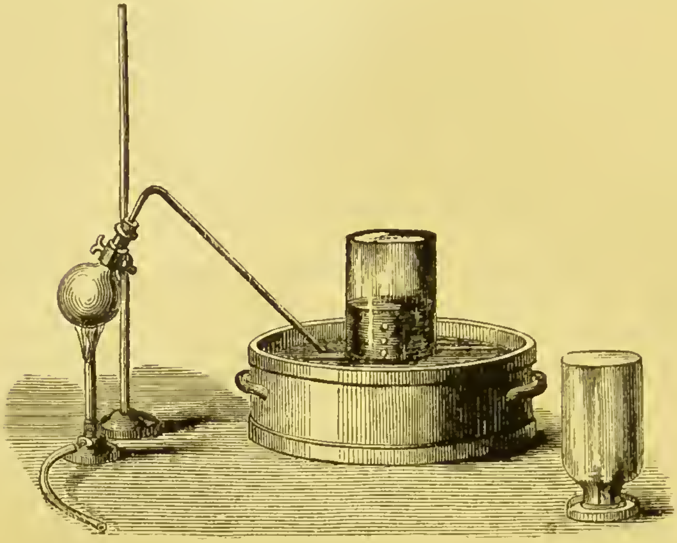


FIG. 15 —Preparation of Oxygen.

$$KClO_3 = KCl + O_3.$$

Oxygen gas may also be obtained by strongly heating in a hard glass tube a red powder called mercuric oxide. This splits up into the metal mercury, which can be seen to collect on the cooler parts of the tube as a metallic mirror, and the gas oxygen. This change may be represented thus :

$$HgO = Hg + O.$$

We can now proceed to examine this gas. Among its properties we notice that it is colourless and without smell. In one of the jars place a glowing splinter, that is, a splinter with only a red-hot tip at the end. The wood at once bursts into flame and burns vigorously. Now take a little sulphur and put it into a small iron spoon called a deflagrating spoon. Set fire to the sulphur, and notice that it burns with a pale blue flame. Plunge the lighted sulphur into a jar of oxygen, and it will burn much more brightly, though the oxygen itself does not burn. We thus learn from these experiments *that oxygen is a colourless gas that supports combustion, and that substances burn in oxygen with much greater energy than in air.* Many substances which will scarcely burn at all in air burn violently in oxygen. Even iron can thus be made to burn in oxygen. If we make a watch-spring red-hot for a short time it loses its elasticity, and can be twisted into the form of a spiral after cooling. Fasten one end of this spiral into a piece of cork, and dip the other end into a little powdered sulphur. Set fire to the sulphur and immediately plunge it into a jar of oxygen. The sulphur sets fire to the steel spring, which burns with great splendour, and drops of melted oxide of iron fall down ($Fe_3 + O_4 = Fe_3O_4$). It must be carefully noticed that while these different substances have been burning they have not been destroyed; that is, they have not disappeared entirely and gone into nothing. They have entered into combination with the oxygen, and new substances have been produced. No element can be destroyed; it can be made to change its form and enter into new combinations, but it still exists. Hence *matter is indestructible.* Wood contains, along with other things, the element carbon, and during the process of burning or combustion this carbon unites with the oxygen to form an invisible gas called carbonic acid. We represent this chemical action thus:

$$C + O_2 = CO_2.$$

If we close the mouth of the oxygen bottle in which a splinter is burnt, then pour in a little clear lime-water and shake it up, we shall notice that the lime-water becomes milky. This proves that the bottle contains something beside oxygen, for on shaking a bottle of pure oxygen with lime-water no milkiness is produced. The milkiness is caused by the carbonic acid uniting with the lime in the water to form an insoluble substance called calcium carbonate. On burning the sulphur a pungent smell was noticed. This is produced by a gas called sulphur dioxide, which is formed when sulphur burns in air or oxygen ($S + O_2 = SO_2$). On placing a little water in the jar in which sulphur has been burnt, this sulphur dioxide is dissolved, and the water acquires a sour taste and the power of turning blue litmus red. Bodies possessing this taste and this power are called *acids.*

We thus see that when bodies burn in oxygen neither the substance burnt nor the oxygen is destroyed, but that they unite together to form chemical compounds, and that these compounds possess properties different from their constituents.

73. **Oxides and Oxidation.**—Oxides are binary compounds formed by the union of oxygen with other elements. The process of uniting with oxygen is called oxidation. Thus carbonic acid (CO_2), sulphur dioxide (SO_2), lime or calcium oxide (CaO), soda or sodium oxide (Na_2O), and phosphorous pentoxide (P_2O_5) belong to this class of compounds. Some elements, as iron, form more than one oxide. We have Fe_2O_3, ferric oxide, and Fe_3O_4, magnetic oxide or triferric tetroxide. The oxides formed by the union of oxygen with the non-metallic elements (except water, H_2O) are compounds which dissolve in water to form *acids.* Many of the metals by their union with oxygen form oxides of an opposite character, called *bases.* Some of these dissolve in water, and produce liquids of a soapy, disagreeable taste. They restore the blue colour to litmus reddened by an acid, and are said to possess alkaline properties. Acids and bases thus

neutralise one another, and the compounds formed by their reaction are called in chemistry *salts.*

74. **Combustion.**—Oxidation is a chemical action, and like other chemical actions is accompanied by a development of heat. Sometimes, as when iron rusts or organic matter decays, oxidation goes on very slowly. At other times the oxidation goes on so rapidly, and the heat developed is so great, that light is produced. It is then called *combustion.* Thus, combustion is rapid chemical action attended with great heat and light. In ordinary combustion the fuel or substance burnt (coal, coal gas, wax, tallow, &c.) consists of compounds of carbon and hydrogen. The products of this combustion are two oxides—carbonic acid, CO_2, and water vapour, H_2O.

75. **Preparation and Properties of Hydrogen.**—Hydrogen is another important gas that can be easily prepared and collected, so that its properties may be ascertained. To do this we require a flask with a cork that has two holes bored in it. Into one of these holes we place a funnel having a thistle-shaped cup at the top, so that liquid can be poured down it into the flask. Into the other hole of the cork the bent delivery tube is placed to carry the gas given off to the pneumatic trough. Before placing the cork into the flask we put in a few pieces of zinc. Then the cork with the tubes is put in, and sufficient water is poured down the thistle funnel to cover over the zinc to the depth of half an inch. A small quantity of sulphuric acid is now added to the water, and the zinc soon begins to react with the dilute sulphuric acid, and a brisk bubbling or effervescence is caused by the escape of hydrogen gas. At first the hydrogen is mixed with the air that was in the flask, but after a short time it comes off pure. Two or three jars may now be collected in the same way as the oxygen was collected.

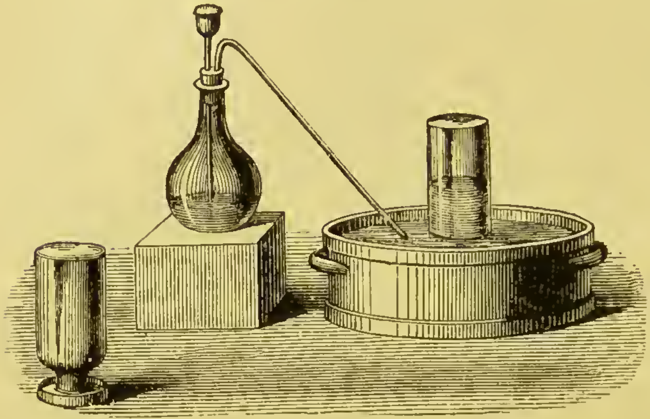


FIG. 16.—Preparation of Hydrogen.

Take a jar of the colourless hydrogen thus collected, and keeping its mouth downwards put into the jar a lighted taper. The hydrogen takes fire and burns with a pale blue flame, but the taper on being pushed into the jar goes out. We thus see that hydrogen is a combustible gas, but not a supporter of combustion. Take another jar and turn its mouth upwards; leave it thus for about half a minute, and then bring a lighted taper to the mouth. No effect is produced, as the gas has all passed into the atmosphere. Hydrogen is the lightest of all gases, and when a jar is left mouth upwards for only a short time all the hydrogen escapes into the air. When hydrogen burns it unites with the oxygen of the air to form water, $H_2 + O = H_2O$ (see Combustion).

76. **Water—Chemical Composition of Water—Synthesis and Analysis.**—Whether water exists in the form of solid

ice, of a liquid, or of a gas, it has the same chemical composition, and always consists of hydrogen and oxygen chemically united. The formula of water is H_2O, and since the atomic weight of hydrogen is 1 and of oxygen 16, we have 2 parts by *weight* of hydrogen to 16 parts by *weight* of oxygen, *i.e.* water consists of eight-ninths of oxygen by weight and one-ninth of hydrogen by weight; but its composition can be proved in two ways—by synthesis and by analysis.

Synthesis (Gr. *syn*, together; *thesis*, a putting) is the building up of a compound out of the elements that compose it. To prove that water is produced synthetically when hydrogen burns in air or oxygen, we take the apparatus used for preparing hydrogen, and in place of the delivery tube we arrange the apparatus as shown in the figure. The thicker horizontal tube is called a drying tube; it contains pieces of calcium chloride in order to dry the hydrogen, so that we may be sure that no water vapour is carried along in the escaping gas. A perfectly dry tube is prepared, and after the gas has been escaping some time so that all the air is carried out, we light the escaping gas and bring over it the dry tube. The water vapour formed by the combustion of the hydrogen is condensed on the cold sides of the tube, and drops of water may be seen trickling down. Thus water is proved to be formed when hydrogen burns.

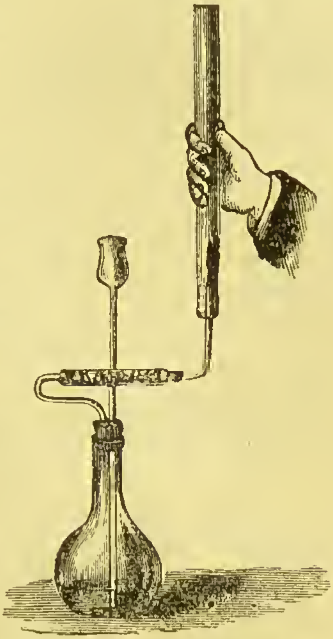


FIG. 17.—Synthesis of Water.

On mixing oxygen and hydrogen in a stout soda-water bottle in the proportion of one volume of oxygen to two volumes of hydrogen, and applying a light, the two gases unite with a loud explosion to form two or three drops of water.

Analysis (Gr. *ana*, apart; and *lusis*, a loosening) is the breaking up a compound into the elements that compose it. To analyse water—that is, to separate it into its two elements—we require the aid of electricity from a galvanic battery. This electricity has the power of decomposing water so as to split it up into its constituent elements. The apparatus required is called a voltameter, and is shown in the figure. The wires proceeding from a battery are made to pass into the vessel V, and at the ends of these wires a piece of platinum-foil is attached. The water in the vessel V is slightly acidulated with sulphuric acid, in order to make it a good conductor of electricity. Two tubes are filled with the same kind of water, and placed mouth downwards in the vessel V, so that one of the platinum terminals at the end of each wire is under the mouth of each tube. On setting the galvanic battery in action the electricity passes into the water, and gas bubbles are seen to rise from each slip of platinum, and these collect in the tubes placed to receive them. More gas is given off from one pole than from the other, and when one tube is full the other is only half full. Take away the tube first full, keeping the thumb over the end. Invert the tube, quickly remove the thumb, and apply a light. The gas burns with a pale blue flame, showing that it is hydrogen. After the second tube is filled, it may be removed in the same way, and dipping a glowing splinter into this gas, the wood bursts into flame, and the gas is thus seen to be oxygen. This proves analytically that water consists of two *volumes* of hydrogen united to one *volume* of oxygen.

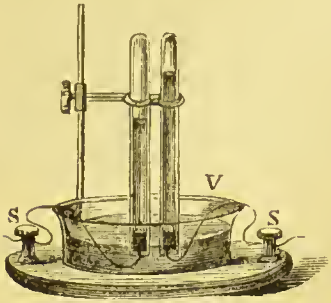


FIG. 18.—Analysis of Water.

77. **Carbon** is found free in nature as diamond and as graphite. Diamond is a crystallised form of carbon, the crystals of diamond having an octohedral shape. Diamond is the hardest substance known, has a specific gravity of 3·3, and when burnt in oxygen by means of an electric current, forms carbon dioxide, CO_2, just as other forms of carbon do.

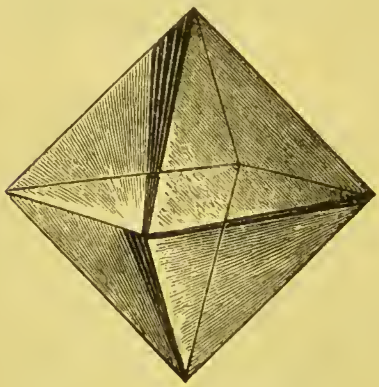


FIG. 19.—Diamond Crystal.

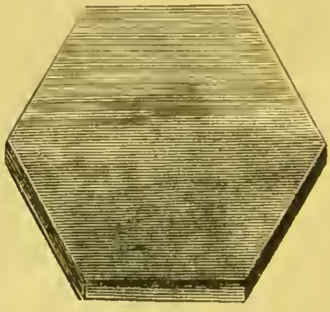


FIG. 20.—Crystal of Graphite.

Graphite, also called plumbago or black-lead (though it contains no lead), is also a natural variety of carbon, sometimes found crytallised in hexagonal plates, and is much used for making black-lead pencils. Its specific gravity is only 2·2, but it is shown to be carbon because it yields the same gas on combustion as other varieties of carbon.

Carbon also occurs in different artificial substances, as charcoal, coke, soot, lampblack, &c. By placing one or two pieces of wood in a test-tube of hard glass, and strongly heating this in a slanting position, a piece of wood charcoal may be prepared. Steam, white fumes, and a tarry liquid are driven out of the wood, and the charcoal is left behind.

78. **Oxides of Carbon.**—Carbon unites with oxygen to form two oxides, carbon monoxide (CO) and carbon dioxide (CO_2). Carbon dioxide is also known as carbonic acid and carbonic anhydride. This last oxide contains twice as much oxygen as the other, and it is so important a gas that we must give particular attention to the way of preparing it, and to its chief properties. As already explained in speaking of combustion, carbon dioxide is produced when carbon, or any substance containing carbon, is burnt in air or oxygen ($C + O_2 = CO_2$). If we burn a candle fastened to a wire in a long glass cylinder containing air, and cover the mouth of the cylinder with a piece of paper, we shall see that the candle burns brightly at first, but soon becomes feeble, and at last goes out. It goes out because it has used up the oxygen in the formation of carbon dioxide. Animals give off carbon dioxide during the process of breathing, and it is one of the gases produced during the *decay* of organic bodies. There are, however, other interesting modes of preparing this gas. Limestone or chalk is a chemical compound called calcium carbonate, and contains three elements, a metal calcium, the solid carbon, and the gas oxygen. Its chemical formula is represented thus: $CaCO_3$. If this limestone be strongly heated it suffers decomposition, for carbon dioxide is driven out of it, and the oxide of calcium is left behind. We can represent this change thus: $CaCO_3 = CaO + CO_2$. This means that the calcium carbonate splits up into the two binary compounds, calcium oxide or lime (CaO) and carbon dioxide (CO_2). This is an experiment carried on every day on a large scale in great furnaces called limekilns. The carbon dioxide escapes into the air, and the lime is left behind as a white hard solid. This white hard solid, CaO, is often spoken of as *quicklime.* On adding water to the quicklime, chemical union takes place, with the development of so much heat that some of the water is turned into steam. Quicklime united to water forms slaked lime ($CaO + H_2O = CaH_2O_2$). We cannot, however, easily collect the carbonic acid driven out of limestone by heat. But there is a way in which this gas can be collected. To do this we place a few pieces of calcium carbonate in a bottle fitted up as shown in the figure. Limestone, chalk, and marble are all forms of calcium carbonate, so that pieces of any of these substances will serve. Carbonates are a class of bodies formed by the union of carbonic acid (CO_2) with the oxide of a metal, and one of the most distinguishing marks of carbonates is that they effervesce when any acid is added to them. This effervescence or bubbling is simply due to the carbon dioxide that is driven off. If, then, we add to the pieces of calcium carbonate placed in the bottle some dilute hydrochloric acid, the carbon dioxide is driven off. The gas may either be collected at the pneumatic trough, or, as it is 1½ times heavier than air, it may be collected by simply allowing it to fall down to the bottom of the jar and gradually lift out the lighter air.

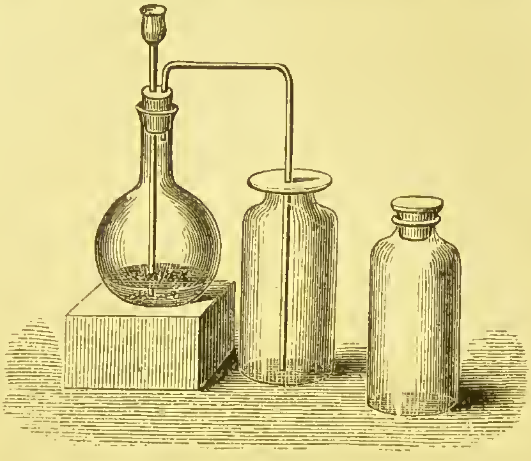


FIG. 21.—Preparation of Carbon Dioxide.

Carbon dioxide is a colourless gas that is neither combustible nor supports combustion. If a lighted candle be placed in a jar of the gas, it is at once extinguished. A small animal placed in a jar of the gas is soon killed. Water dissolves about its own volume of the gas, and the solution of carbon dioxide in water has a feeble acid taste. To prove the presence of carbonic acid the following *test* is employed. A small quantity of lime (CaO) is dissolved in water, and the clear solution obtained is called lime-water. On adding lime-water to a vessel containing carbonic acid the lime-water becomes milky, owing to the formation of insoluble calcium carbonate, which is said to fall down or be precipitated. The lime in the water unites with the carbon dioxide to form the calcium carbonate thus: $CaO + CO_2 = CaCO_3$. It is the particles of this white insoluble calcium carbonate that give the water its milky appearance. It is of great importance to notice that calcium carbonate is insoluble in pure water. If, however, we take some lime-water in a glass beaker, and cause carbonic acid to bubble through it for a considerable time, we shall be able to notice that although it becomes milky at first, yet, on continuing to bubble in more carbonic acid, it becomes clear. We thus learn that although, as stated above, calcium carbonate is quite insoluble in pure water, *it dissolves in water which contains carbon dioxide in solution.* On boiling the clear solution just obtained the carbon dioxide is driven off, and the calcium carbonate is again precipitated. Rain-water dissolves a little carbonic acid as it falls through the air, and it obtains more as it percolates through ground containing decaying animal and vegetable matter. In this way it becomes able to dissolve calcium carbonate, and in those parts of the country where chalk and limestone rocks abound parts of the rocks are slowly dissolved away, and the water of the springs and streams contains small quantities of calcium carbonate in solution. Such water is called 'hard water,' and when used for washing purposes it only 'lathers' with difficulty. Water which contains no calcium salts in solution, such as pure distilled water, or rain-water as it falls, is 'soft,' and the soap 'lathers' easily with such water.

79. **Distinction between Compounds and Mixtures.**—We must carefully distinguish between mixing things together, and causing them to unite together so as to form a new compound. In some few cases elements unite at once on being brought into close contact, but frequently heat, electricity, or some other force must be used to bring about chemical union. If we take some iron filings and sulphur we may mix them together in any proportion, but they do not unite. With a magnifying glass the particles of the iron and the sulphur can be separately distinguished, and by throwing the mixture into water we shall see that most of the heavy particles of iron sink at once to the bottom, whilst the lighter sulphur either floats or sinks much more slowly; or we may dip a magnet into the mixture, and in this way the magnet, which attracts iron and not sulphur, may be made to pull out all the metal and leave the sulphur behind. Now take fifty-six parts by weight of iron and thirty-two parts by weight of sulphur, and heat the mixture in a hard glass tube. After a time you see a deep red glow quickly spread through the mixture as chemical union takes place. If now you examine the material, you will see that you can no longer distinguish the iron and the sulphur separately, nor is the substance any longer attracted by the magnet. A new substance has been formed, having properties different from those of the two elements composing it. This new substance is a chemical compound called sulphide of iron. Notice, then, (1) that in a *mixture* the substances can be separated

by mechanical means, and that the substances forming the mixture may be mixed in any proportion, while the properties of a mixture partake of the properties of the substances put together; (2) that in a compound the substances unite together so that they cannot be separared by mechanical means, and the union takes place in certain definite proportions, viz. that of their atomic weights or simple multiples thereof, and that the compound is a new substance, possessing properties different from the elements composing it.

80. **Distinction between Physical and Chemical Changes in Matter.**—If we take a piece of iron and heat it till it becomes red-hot, it is still iron. Hot iron has the same composition as cold iron. If we take the piece of iron and magnetise it with a magnet, so that it will attract other pieces of iron, it is still iron; for magnetised iron has the same composition as iron not magnetised. The changes that the iron has undergone have given it new properties, but they have not altered its composition. Such changes are called *physical* changes, and the physical properties of a body refer to its condition, whether solid, liquid, or gaseous. Hardness, colour, density, crystalline form, and the state of the body as regards its heat and electricity are physical properties. But wherever there is a chemical change, whether it take place slowly or quickly, we have a change in *composition*. Thus if iron be exposed to moist air, it takes up something from the air, and becomes covered with a red substance called rust. Rust is a new substance, of a different composition as well as of a different colour, and with the force of cohesion much less than in the iron; and as it is formed by the chemical union of iron and oxygen, it is a compound. The formation of rust is an example of a chemical change. The only property that chemical action is powerless to alter is that of weight. There is neither loss nor increase of weight in any chemical action, for matter can neither be created nor destroyed. 16 parts by weight of oxygen, whether grains or ounces or pounds, always unite with two parts by weight of hydrogen to produce 18 parts by weight of water. When iron rusts, the oxide of iron thus formed (Fe_2O_3) is equal in weight to the iron and oxygen that enter into combination, twice 56 parts by weight of iron (56 is the atomic weight of iron) uniting with three times 16 parts by weight of oxygen. If pure marble (calcium carbonate) be strongly heated, it is decomposed into quicklime (CaO) and carbon dioxide (CO_2), and the united weights of the substances thus produced are equal to the weight of calcium carbonate taken.

81. **Laws of Chemical Combination.**—The student is now able to understand the fixed laws which regulate the relative proportions in which the elements unite to form the numerous compounds.

Law 1.—*The same chemical compound always contains the same elements united together in the same proportions.* This may be called the *law of constant composition* or *fixed proportions*. Water (H_2O) *always* consists of 16 parts by weight of oxygen united to 2 parts by weight of hydrogen, so that in 100 parts by weight of water there will be 88·8 parts by weight of oxygen and 11·1 parts by weight of hydrogen. Carbonic acid (CO_2) is always composed of 12 parts by weight of carbon and 32 parts by weight of oxygen, its per-centage composition being invariably $27\frac{3}{11}$ of carbon and $72\frac{8}{11}$ of oxygen.

Law 2.—*When two elements are capable of uniting in more than one proportion, these proportions will be a simple multiple of each other.* Thus carbon forms two compounds with oxygen, carbon monoxide (CO) and carbon dioxide, or carbonic acid (CO_2). In the first we have 12 parts by weight of carbon uniting with 16 parts by weight of oxygen, and in the second we have 12 parts by weight of carbon uniting with *twice* 16 parts by weight of oxygen. We have never a compound of oxygen formed in which a fractional part of 16 is taken, but always some multiple of 16. So for other elements. Each atom of one element unites with 1, 2, or 3 atoms of the other element, or in some other simple ratio, because the atom is indivisible. This is called the *law of multiple proportions.*

Law 3.—*Each element in combining with other elements, or in displacing others from their compounds, does so in a fixed numerical proportion.* This is known as the *law of equivalent proportions.*

Law 4.—*The combining or molecular weight of a chemical compound is the sum of the combining weights of the atoms of the elements composing it contained in a molecule of the compound.* This may be called the *law of molecular weights.*

82. **Modes of Chemical Action.**—Most examples of chemical change may be referred to the following divisions :—

(1) Cases of direct combination of elements (formation of a compound by *synthesis*) :

$$\underset{\text{Sulphur.}}{S} + \underset{\text{Oxygen.}}{O_2} = \underset{\substack{\text{Sulphur}\\\text{dioxide.}}}{SO_2}$$

(2) Cases of simple decomposition (*analysis* of a compound) :

$$\underset{\text{Water.}}{H_2O} = \underset{\text{Hydrogen.}}{H_2} + \underset{\text{Oxygen.}}{O}$$

(3) Cases of decomposition by substitution or displacement :

$$\underset{\text{Zinc.}}{Zn} + \underset{\substack{\text{Sulphuric}\\\text{acid.}}}{H_2SO_4} = \underset{\substack{\text{Zinc}\\\text{sulphate.}}}{ZnSO_4} + \underset{\text{Hydrogen.}}{H_2}$$

(4) Cases of double decomposition :

$$\underset{\substack{\text{Hydrochloric}\\\text{acid.}}}{2HCl} + \underset{\substack{\text{Calcium}\\\text{carbonate.}}}{CaCO_3} = \underset{\substack{\text{Calcium}\\\text{chloride.}}}{CaCl_2} + \underset{\text{Water.}}{H_2O} + \underset{\substack{\text{Carbon}\\\text{dioxide.}}}{CO_2}$$

CHAPTER VI.

ROCKS—THEIR COMPOSITION, CLASSIFICATION, AND ARRANGEMENT.

83. HAVING now learnt something about the properties of matter, and the various forces which act upon it so as to produce changes in it, and understanding the difference between physical and chemical changes, we are ready to begin a more

particular inquiry into the different masses of matter which make up our globe, the land, the sea, and the surrounding air. We will begin with the solid part of the globe, which we call the land.

84. **Meaning of Crust.**—The science which treats of the composition, arrangement, and changes of the materials forming the solid part of the earth is called Geology. Geologists often speak of the 'crust of the earth.' By this term we are to understand the exterior portion so far as it has been brought under our observation and reasoning. Hence the term crust is used to denote the 'upper or outer layers of the earth's mass.' We have no means of knowing what is now the real structure and condition of the earth's interior, but by inspecting quarries, railway cuttings, sea cliffs, ravines, wells, mines, and the materials sent out by volcanoes, we can learn something about the outer parts of the solid earth, and it is to this outer portion that we refer when we speak of the 'crust.' The total thickness of the earth's crust penetrated by man is only a few thousand feet, and the highest mountains are not more than 30,000 feet high. Although our reasoning may lead us to infer something about the rocks to a depth of nearly fifty miles, yet, considering that the centre of the earth is nearly 4,000 miles from the surface, we have only knowledge of but a small fraction of the earth's radius.

85. **Definition of Rock.**—Every one has noticed that the solid parts of the earth consist of distinct substances, such as clay, limestone, chalk, sand, coal, peat, granite, &c.; and to these several substances which form the materials of the earth's crust we give the name *rock*. Some are hard and firm, others are soft and loose; but all alike are called rocks. Hence we see that while in ordinary language the word rock denotes a great mass of hard stone, in geology *a rock is any mass of natural substance forming part of the earth's crust.* In this sense, loose sand, gravel, and soft clay are as much rocks as hard limestone and granite.

86. **The Materials of which Rocks are composed.**—Rocks are formed of various materials called minerals. If we take a piece of sandstone rock, or a piece of granite, we shall probably be able to notice that the rock is made up of different substances.

87. Let us first examine a specimen of *sandstone*. On looking at it carefully, especially if we use a magnifying glass, we see that it is composed of little rounded grains of a glassy-looking substance cemented together. In some specimens these grains are larger than in others. This cementing material is not the same in all sandstones, but in our specimen it is formed of calcium carbonate, for when we drop a little dilute hydrochloric acid on

the rock there is an effervescence. The cementing material is dissolved, but the little rounded grains, which consist of quartz, are not affected by the acid. The sandstone, then, consists of quartz grains cemented together by calcium carbonate. It is called a calcareous sandstone.

88. Now take a piece of *granite*, and break it with a hammer to get a clean-cut face. On looking at this face we see that the rock is made up of three different substances.

One of these has a glassy appearance like the grains in the sandstone, and is so hard that we cannot scratch it with a knife. This is quartz. Another of the substances is of a dull white or pinkish colour. It lies in long smooth-faced crystalline patches, which easily break along a number of smooth parallel surfaces having a pearly lustre. It can be scratched with difficulty by the point of a knife. This substance is called felspar. The third substance consists of bright glistening plates, sometimes of a dark colour, which can be easily scratched, and which readily split into transparent leaves. This is mica (Lat. *mico*, to glisten). Notice that these substances do not occur in any definite order, but are scattered about through the stone irregularly, the felspar occurring in some specimens in larger crystals than in others.

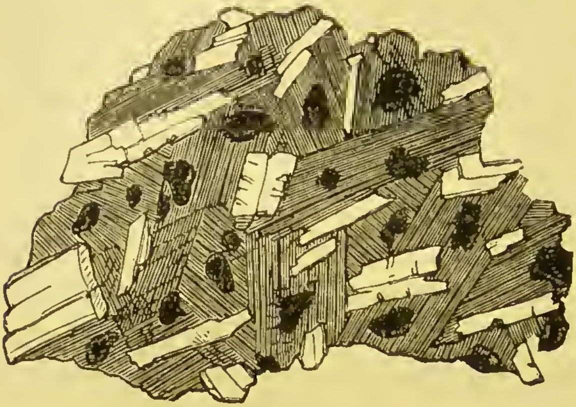


FIG. 22.—Piece of Granite (crystals of felspar light, of mica black).

Hence we see that granite consists of a mixture of three substances, called quartz, felspar, and mica, the felspar being in greatest quantity. Each of these substances possesses properties more or less peculiar to itself, such as hardness, solubility in acids, specific gravity, crystalline form, way of splitting, &c. Moreover, each of these substances has a constant chemical composition.

Thus quartz is a binary compound known in chemistry as silica, and a molecule always consists of one atom of silicon united to two atoms of oxygen (SiO_2). The calcium carbonate is represented by the formula $CaCo_3$. It is a ternary compound, formed of the three elements calcium, carbon, and oxygen chemically united. It may also be regarded as formed of the two oxides, CaO, calcium oxide or quicklime; and CO_2, carbon dioxide (CaO,CO_2).

Felspar contains four elements. Its formula may be thus represented: $Al_2O_3,K_2O,6SiO_2$. This shows it to be made up of three oxides, Al_2O_3, alumina; K_2O, potash; SiO_2, silica.

89. Bodies like these, which have a definite chemical composition and constant physical properties, are called minerals; and rocks are formed either of one mineral, or more generally of a mechanical mixture of minerals. Hence we give the

following definition of a mineral:—*A mineral is a naturally formed inorganic substance which has a constant chemical composition and constant physical properties.* This definition may be understood to include such substances as coal and chalk, which are the mineralised remains of plants and animals respectively. Even water and the gases of the atmosphere may be said to belong to the mineral kingdom of nature, as plants and their parts are said to belong to the vegetable kingdom, and animals and their parts to the animal kingdom.

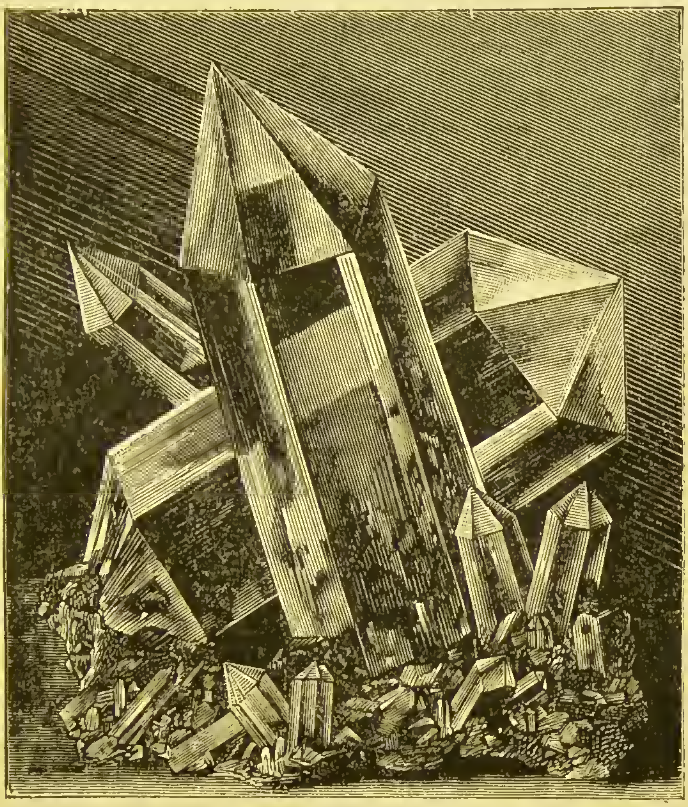


FIG. 23.—Crystals of Quartz (rock-crystal). The lines on the crystals only indicate shading.

90. **Ores** are minerals from which useful metals may be extracted. Thus tinstone, or oxide of tin (SnO_2), galena, or sulphide of lead (PbS), and red hematite, or ferric oxide (Fe_2O_3), are ores. The metallic ores occur scattered through other rocks chiefly in narrow veins or threads, called *metallic veins.*

Some metals are found free, that is, uncombined with any other element, and they are then said to be *native.* Gold, silver, platinum, and copper are found native.

91. **Chief Rock-forming Minerals.**—The total number of rock-forming minerals is very large, but many of them are very rare, and form but a very small part of the earth's crust. The special study of minerals belongs to a science called Mineralogy. A few of the most important minerals will now be described.

92. **Quartz.**—As already mentioned, this mineral consists of pure silica, and when crystallised is known as rock-crystal. The crystals when complete consist of six-sided prisms terminated at each end by six-sided pyramids. (See par. 31.)

Natural crystals, however, are seldom perfect and regular at both ends (see fig. 23). They are often matted together, and some of the faces extended at the expense of others. But the angles formed by the meeting of the faces are always of exactly the same size for the same kind of mineral. Rock-crystal when pure is colourless, when slightly tinted with purple it is called *amethyst*, and when tinted yellow it is called *cairngorm*.

The non-crystalline or amorphous varieties of quartz are—*Chalcedony*, a semi-transparent, waxy-looking form of quartz. *Agate*, a variety of quartz coloured by metallic oxides, the colours being often arranged in concentric bands. It is often cut for brooches and other ornaments. *Flint*, a dark-coloured, dull-looking variety of silica, which breaks with a shell-like fracture. It often occurs in irregularly shaped nodules in chalk. *Hornstone* and *chert* are impure varieties of flint.

93. **Felspar.**—Silica enters largely into combination with other bases to form a class of compounds called *silicates*. A silicate is formed by the union of silica with the oxides of metals, the metallic oxides being called bases. These silicates take a large share in the composition of the rocks called *igneous* and *metamorphic* (see Classification of Rocks). Common felspar is a silicate of alumina and potash, and its composition may be represented thus: $Al_2O_3,3SiO_2 + K_2O,3SiO_2$. It thus contains four elements, and may be looked upon as consisting of three oxides chemically united. Its colour varies from white to light red. Its crystals have the shape of an oblique rhombic prism. It is only scratched by a knife-point with difficulty. Some varieties of felspar contain soda (Na_2O) or lime (CaO) instead of potash. Felspar is the most abundant mineral.

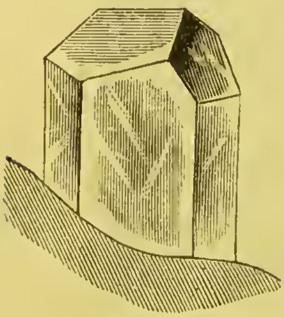


FIG. 24.—Crystal of Felspar.

94. **Mica.**—This mineral is also a silicate. There are several kinds of mica, but all contain silica, alumina, and potash, and the mineral is easily distinguished from others by readily splitting into laminæ or thin plates, which are both flexible and elastic. It is soft enough to be scratched by the finger-nail. It derives its name from its glistening appearance.

Other minerals composed of silicates are *talc*, *serpentine*, *olivine*, *augite*, and *hornblende*.

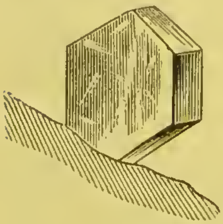


FIG. 25.—Crystal of Mica.

95. **Calcite** is the name given to the mineral formed by the union of oxide of calcium and carbonic acid, $CaO + CO_2$. Its chemical name is calcium carbonate, or carbonate of lime ($CaCO_3$). It is easily scratched with a knife, and dissolves with effervescence in hydrochloric acid. There are several varieties of this mineral. Iceland spar

is the pure transparent form, having its crystals in rhombohedrons, and exhibiting the curious optical property of double refraction.

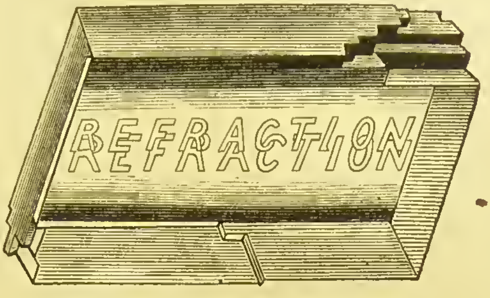


FIG. 26.—Crystal of Iceland Spar.

Dog-tooth spar and nail-head are other crystalline forms of calcite.

96. **Varieties of Calcite or Calcium Carbonate.** — *Statuary marble* appears in minute granular crystals matted together. *Limestone* is mostly an amorphous form of calcium carbonate. *Stalactites* are semi-translucent masses of calcium carbonate found hanging on the roofs of some caves. *Stalagmites* are similar masses found on the floors of caves. *Travertine* is a calcareous deposit from springs which have contained calcium carbonate in solution. As the water gives off carbon dioxide, and also as it evaporates, the calcium carbonate is deposited. When light and porous this deposit is called calcareous tuff or tufa.

97. **Dolomite**, or magnesian limestone, is a mixture of calcium carbonate and magnesium carbonate.

98. **Gypsum** is a mineral composed of calcium sulphate, or sulphate of lime ($CaSO_4$). It is easily cut with a knife, and does not effervesce with an acid.

Selenite is a crystallised transparent variety of gypsum.

Alabaster is an amorphous translucent variety of gypsum.

99. **Barytes**, or heavy spar, is a sulphate of barium ($BaSO_4$). It is a very heavy mineral of a white colour, and often found in mineral veins. It can be scratched with a knife, but is insoluble in acids.

100. **Rock-salt** has the same chemical composition as ordinary table salt, and is known to chemists as sodium chloride ($NaCl$). It crystallises in cubes.

101. **Carbon** is found as a mineral in two forms: as *diamond*, which is the hardest of all minerals; and as graphite, plumbago, or black-lead. This last form was called black-lead because of its resemblance to the metal lead, but it has no lead in it, being nearly pure carbon.

102. We may here point out the relative abundance of the various *elements* forming the above minerals, as well as the most abundant of the *minerals* themselves entering into the *crust* of the earth. The following tables, giving (1) the per-centage by weight of the elements in the earth's crust, and (2) the per-centage of the minerals in the earth's crust, are based on the assumption that the earth's crust consists of 3 miles of stratified rocks and 57 miles of unstratified or igneous rocks. They are given on the authority of Professor Prestwich.

I. *Per-centage of Elements in the Earth's Crust.*

1.	Oxygen	50·0	7.	Potassium	1·6
2.	Silicon	25·0	8.	Carbon	2·4
3.	Aluminium	10·0	9.	Iron	
4.	Calcium	4·5	10.	Sulphur	
5.	Magnesium	3·5	11.	Chlorine	
6.	Sodium	2·0	12.	Other bodies	1·0

Oxygen is therefore the most abundant element in the earth's solid crust, forming one-half of it by weight. Silicon is next, forming about one quarter of the earth's crust. Oxygen also forms eight-ninths of water by weight, and about one-fifth by weight of the atmosphere.

II. *The Per-centage of Minerals in the Earth's Crust.*

1. Felspar	48
2. Quartz	35
3. Mica	8
4. Talc	5
5. Carbonates of lime and magnesia	1
6. Amphibole (hornblende)	1
7. Pyroxene (augite)	
8. Diallage	
9. Peridot (olivine)	
10. Clay (in all its forms)	1
11. Other substances	1

It is thus seen that felspar is the most abundant mineral; but it is also quite correct to say that silica (SiO_2) is the most abundant compound, for it not only occurs separately as quartz, forming 35 per cent. of the crust, but it occurs in combination with other oxides to form felspar and other silicates mentioned above.

103. **Organic Rock Materials.**—Besides the above minerals that enter into the composition of rocks, there are certain other mineralised substances that form considerable parts of the earth's crust, and which, being derived from the animal and vegetable world, are spoken of as *organic rock material*; for only animals and plants have organs. The opposite of organic is inorganic or mineral. Coal, peat, and amber consist of organic matter derived from plants; chalk and coral are organic matter derived from minute animals. Hence they are not, strictly speaking, minerals, though often included under that name, and reckoned in the per-centage estimates just given.

104. **Coal.**—Coal consists mainly of carbon, and compounds of carbon with hydrogen.

Plants consist of carbon, hydrogen, oxygen, and nitrogen in various combinations. After vegetable matter has been buried in the earth it suffers decomposition, gives off various gases, such as carburetted hydrogen (CH_4), called also marsh gas, and by colliers fire-damp, carbonic acid, and water, so that the residue becomes richer and richer in carbon.

By compression and alteration they change into peat, lignite, coal, and anthracite. The following table from Roscoe and Schorlemmer's Chemistry, which gives the per-centage composition of these substances, shows that the elements which make up woody fibre are the same as those which make up coal; and as we pass from wood up to the kind of coal called anthracite we see how the per-centage of carbon increases, and how great a decrease there is in the per-centage of O and N.

There is also a slight decrease in the per-centage of hydrogen.

	Carbon	Hydrogen	Oxygen and Nitrogen
Wood	50·00	6·00	44·00
Irish peat	60·02	5·88	34·10
Lignite from Cologne . . .	66·96	5·25	27·76
Earthy coal from Dax . . .	74·20	5·89	19·90
Cannel coal from Wigan . .	85·81	5·85	8·34
Newcastle Hartley . . .	88·42	5·61	5·97
Welsh anthracite	94·05	3·38	2·57

The vegetable nature of peat is plain from its chemical composition, from its fibrous appearance, and from its being found in boggy places where marshy plants grow and decay. That coal also is of vegetable occurrence is proved by its chemical composition, by the fact that peat under very great pressure is changed into a black shining material resembling coal, by the numerous fossil plants found in coal, and by the fact that when a thin slice is examined under the microscope vegetable tissues and cells are distinctly visible.

When peat and coal are burnt they pass off as gases, leaving a small quantity of incombustible mineral matter behind, which we call ash.

Lignite, or brown coal, is woody matter mineralised, but not to the same extent as coal.

Amber is the fossilised resin of trees, and is chiefly found on the shores of the Baltic Sea.

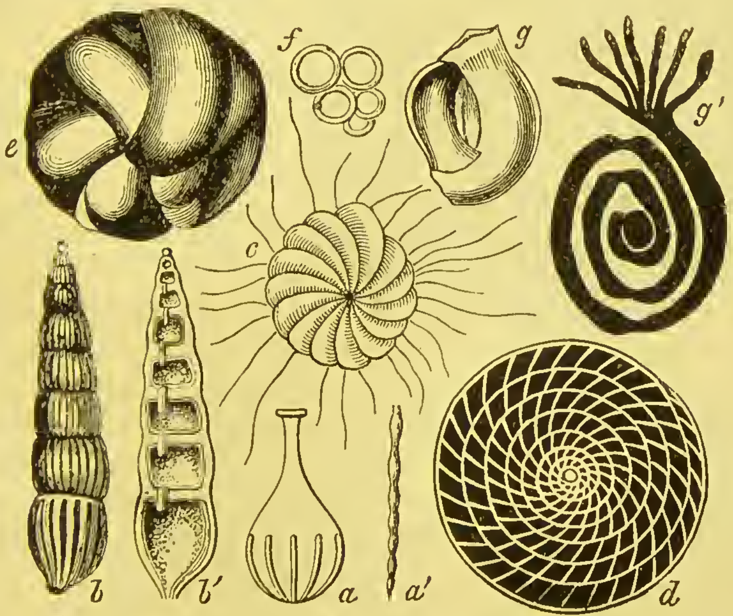


FIG. 27.—Various forms of Foraminifera, highly magnified.

105. All rocks which consist mainly of calcium carbonate are often included under the term limestone, and are said to be calcareous (Lat. *calx*, lime). The hard coverings of many small animals living in water are

secreted or separated from the matter held in solution, and as the animals die their remains accumulate at the bottom. *Chalk* is a white rock composed almost entirely of calcium carbonate, with a few silicious remains.

Rub off a little powder from the chalk into clean water, take a little of the sediment that falls to the bottom after washing, and place it on a glass slide under a microscope ; you will then see a number of minute shells and fragments of shells (see fig. 67*b*). Most of these shells are skeletons of minute animals called Globigerinæ, animals consisting of a mere speck of jelly-like material. The Globigerinæ belong to a group of animals called Foraminifera. Their small soft bodies are enclosed in variously shaped shells, which are usually made up of several chambers, the walls of which are pierced by numerous holes or *foramina*, through which thread-like portions of the animal's body protrude. It is a noteworthy fact that the ooze which is dredged up from many parts of the ocean floor is made up of shells similar to those of which chalk consists, and we thus see the way in which the great beds of chalk, forming what is sometimes called Foraminifera land, have been produced in past ages of the world. Chalk, however, differs from the Globigerina ooze in having a larger proportion of granular particles, and in the absence of a proportion of silicious shells always present in the ooze (see pars. 122 and 187). Both chalk and the ooze contain minute saucer-shaped discs called *coccoliths*, or when gathered into spheroidal masses, *coccosphores*. The foregoing figure shows the shape of some shells of Foraminifera when seen under the microscope. The central one, *c*, shows filaments of the animal's body protruding through the minute pores of the shell. . At *b'* and *d* the shells are shown in section, so that the internal chambers may be seen.

106. There is a variety of limestone called *crinoidal* or *encrinital limestone*. This is composed largely of the calcareous joints of marine animals called sea-lilies, or encrinites, which are attached by means of a jointed stem. Often, after this limestone has been exposed for some time to the action of the weather, parts of these jointed stems are distinctly visible. Polishing such limestone also brings out its structure.

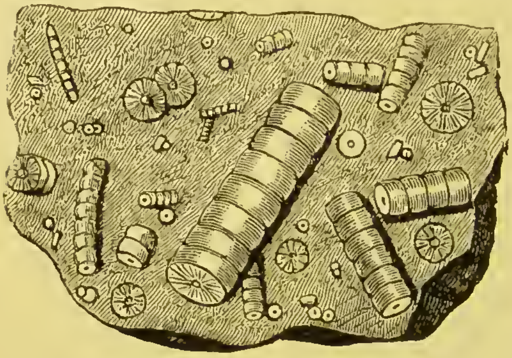


Fig. 28.—Limestone showing Stems of Encrinites.

107. **Coral** is also an organic rock substance, for it likewise consists of calcium carbonate which has been secreted from sea water by certain small gelatinous animals that belong to the class called Actinozoa. This particular kind of Actinozoa is called the coral polyp. Its body is only a mass of soft jelly, with numerous feelers or tentacles at the upper part ; but it has the power of attaching itself to submerged rocks in the sea, and of depositing near the outer and lower part of its body a hard mass of calcium carbonate drawn from the sea in which it lives. It thus becomes fixed, goes on increasing in height and

breadth, multiplying in various ways, as by budding and splitting, each division growing into a perfect polyp, which adds to the mass of hard substance deposited. In this way are formed pieces of coral of considerable size and of varying shapes. When the coral polyp dies the soft parts of its body decay and are washed away, but the hard skeleton remains behind, and accumulates on the floor of the sea to form masses of land —coral reefs and coral islands (see par. 125).

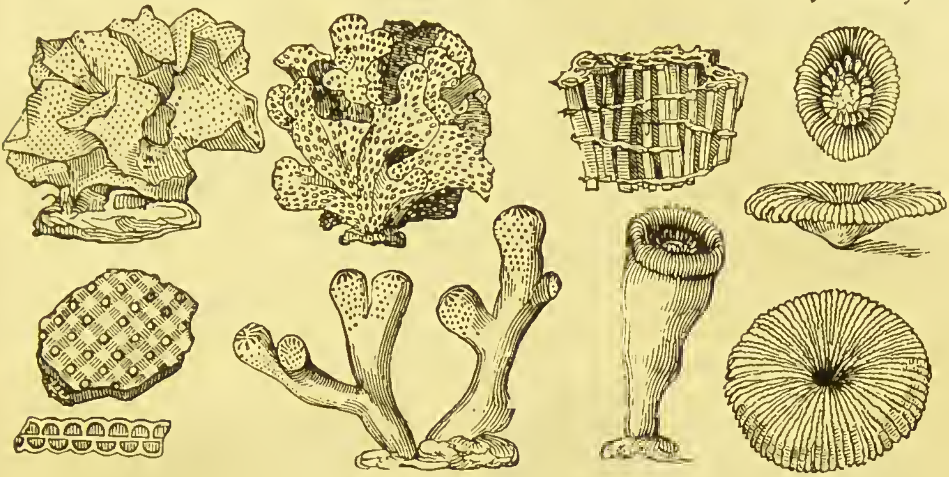


Fig. 29.—Stone Corals.

It must not be supposed that the coral rock is the result of 'work' on the part of the coral polyps, in the sense that a bird works when it builds its nest. The secretion of the calcium carbonate from the sea water is as much an unconscious process as is the extraction from the food of the mineral matter that forms our bones; and the coral land accumulates by the animals dying below, while new animals grow above. There are two classes of the coral polyps—*detached corals*, living in nearly all seas at any depth; and *reef-building corals*, which can live only in clear water within a limit of 20 fathoms from the surface and where the water is above 68° F. Hence coral rocks are only found in the warm waters of the

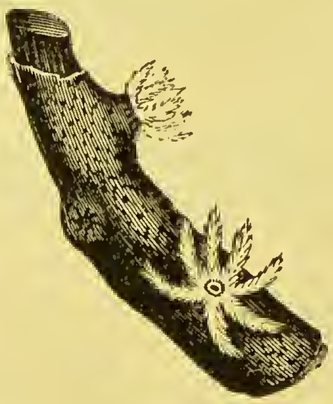


Fig. 30.—Small piece of Coral, magnified, showing the extended Tentacles of the Coral Polyps.

tropical seas. There are many kinds of the coral polyps, and the coral rock is of various forms. Some are shaped like the branches of trees, others resemble tufts of clustered leaves, some form roundish masses, while still others are like groups of coloured twigs. When the animals are living their branching feelers are seen expanded in a great variety of colour and form.

Classification and Description of Rocks.

Having now learnt something about the materials of which rocks are formed, we proceed to give some account of these great masses of rocks themselves, and the mode in which they are arranged in the earth's crust.

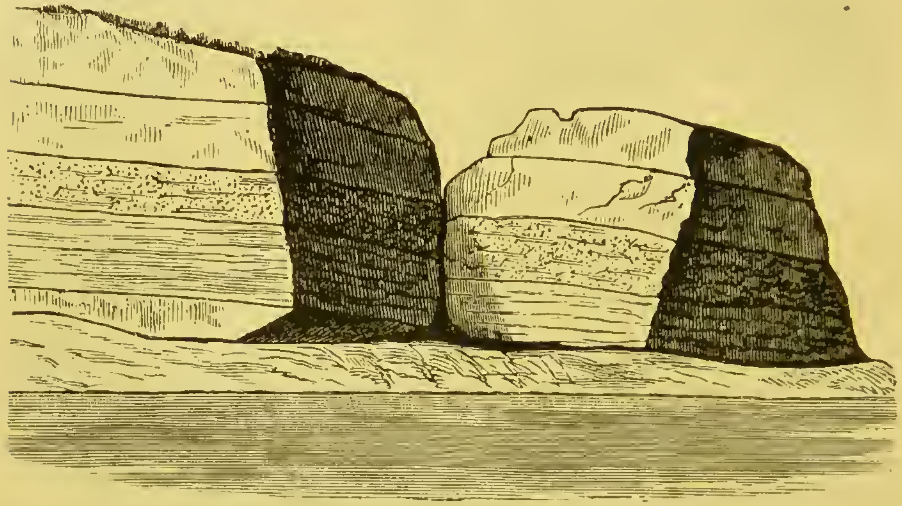


FIG. 31.—Stratified Rocks.

108. Rocks may be classified, according to their mode of origin or mode of formation, into two great classes—*stratified* and *unstratified.* On looking at a sea cliff, a railway cutting, or a quarry, we shall often be able to notice that beneath the soil the rocks are arranged in more or less parallel layers, or *strata*, as they are called. Such rocks are called stratified rocks (Lat. *stratum*, pl. *strata*, what is spread out).

Thus in the figure we see five layers or strata of rocks. Sandstone, clay, limestone, shale, &c., belong to this class.

109. In other cases no traces of beds or layers can be detected, and the rock merely forms a great mass of mineral

matter. Such rocks are called unstratified, and have often a lumpy, massive appearance.

110. As there is every reason to believe that the stratified rocks have been subject to the action of water, having been either mechanically suspended or chemically dissolved in it, these rocks are also called *aqueous* (Lat. *aqua*, water). We believe that these beds or strata have been spread out by the action of water owing to the signs of water-action that they still retain, and also because we can observe at the present time that, whenever a running stream has its velocity checked on entering a lake or the sea, the pebbles, sand, or mud that it brings down are spread out in horizontal layers on the bottom. But the stratified rocks do not always preserve this horizontal arrangement, for they have often undergone displacement and upheaval after their original deposition.

111. The unstratified rocks show many signs of having been subject to the action of intense heat, some of them having evidently been in a molten state, the minerals of which they are composed showing a crystalline structure. Hence they are also called *igneous* (Lat. *ignis*, fire). These rocks are generally found in mountainous districts, and have often been pushed up from below through the overlying strata. In one place they rise up as huge conical hills, in another they may be seen filling up rents and fissures like walls or dykes, while in another district they have spread out on the surface in streams of lava.

It is from the broken-down or disintegrated materials of the igneous rocks that the stratified rocks have been formed in the first instance. Thus by the decomposition of the felspar in granite, clay is produced, and most sand grains have been derived from the quartz of the same rock. These sand grains become consolidated into sandstone, and this in its turn may be broken up again, to again undergo further consolidation.

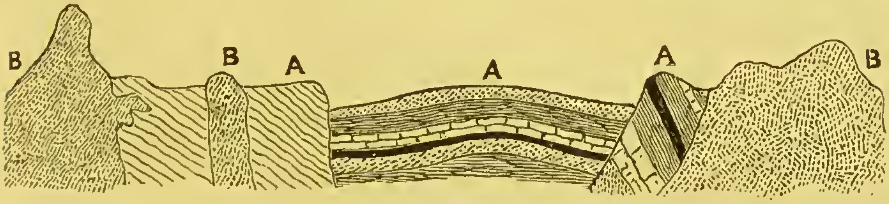


FIG. 32.—A, Stratified Rocks. B, Unstratified Rocks.

112. We will now put the chief differences between these two great classes of rocks into the form of a table.

Stratified or Aqueous Rocks	Unstratified or Igneous Rocks
1. Possess evident marks of bedding.	1. Possess no true marks of bedding.
2. Are derived from previously existing rocks.	2. Are the oldest and primitive rocks.
3. Are situated usually in plains and on the flanks of mountains.	3. Are situated in mountainous districts, and often compose the axis or nucleus of a mountain chain, sometimes filling up long upright fissures, and forming vertical masses called *dykes*.
4. Are formed of minerals which have usually a non-crystalline structure.	4. Are formed of minerals usually having a crystalline structure.
5. Have plainly been deposited one after another from above.	5. Have been erupted or driven out from the interior.
6. Contain the remains or impressions of plants and animals that existed at the time the rocks were deposited. These remains or marks are called fossils, and hence such rocks are called *fossiliferous*.	6. Contain no organic remains except such as were buried in volcanic ashes or mud during an eruption. Hence called *unfossiliferous*.

113. **Metamorphic Rocks.**—Besides the stratified and unstratified rocks, there is another class of rocks which, though originally stratified, have undergone great alterations in structure and composition, whilst traces of fossil remains have been destroyed. These are called metamorphic or transformed rocks (Gr. *meta*, change ; *morphē*, form).

To this class belong clay-slate, quartzite, statuary marble, mica-schist, and gneiss, which will presently be described.

The chief agents concerned in these changes are heat, water, and pressure. Metamorphic rocks are chiefly found next to intrusive igneous rocks ; and it is probably owing to the heated state of these that many of the stratified rocks that adjoin them have been metamorphosed or transformed.

114. **Crystalline and Non-crystalline Rocks.**—The above twofold division of rocks, based on the mode of their formation into (*a*) unstratified or igneous, and (*b*) stratified or aqueous, corresponds closely to another twofold division, which is based on the texture of the rocks, that is, on the arrangement of the particles forming any given rock. As a rule we find that the igneous rocks have a crystalline texture, while the stratified rocks

are non-crystalline. But to this general statement there are some exceptions. In speaking of crystallisation we saw that substances assume those definite geometrical shapes called crystals when they have either been in solution in a liquid or in a molten condition through heat. When in either of these states we know that the particles of many substances have the power of taking up definite positions round a centre as the liquid evaporates or as the fused mass cools, and the crystals are formed by the successive addition of particles to the exterior, large crystals being built up by the regular addition of a number of small crystals. As the igneous rocks are believed to have been at one time in a state of fusion, we find that they usually consist of a network of interlaced crystals and crystalline particles, the crystals being often large enough to be visible to the naked eye, as in granite. In other cases we need to make a very thin section of the rock and examine it under a microscope to see the crystalline texture ; while in the case of a few igneous rocks, such as some lavas, where cooling has taken place rapidly, the rock only shows a glassy or vitreous structure, as in obsidian (volcanic glass). But as these glassy or vitreous rocks often show under the microscope incipient forms or beginnings of crystals, called microliths, or crystallites, in the glassy base, it is usual to include such rocks in the crystalline class. On the other hand, the ashes and other fragmentary materials sent out from volcanoes may be called non-crystalline or fragmental igneous rocks.

The aqueous or stratified rocks, being in all cases formed of materials derived from pre-existing rocks, are usually composed of particles having no definite arrangement and showing no crystalline structure. These fragments out of which the stratified rocks have been formed are of various sizes, from blocks of several feet to exceedingly fine powder, and have been generally massed together irregularly by mechanical compression or the infiltration of some cementing substance. The names given to these various fragmental or non-crystalline rocks, and the mode in which the particles have been bound together into masses, will be explained presently. But where the material from which an aqueous rock has been formed has been in solution in water, the deposit from this aqueous solution possesses a crystalline texture, as in some limestones formed from precipitated calcium carbonate. Beds of gypsum (calcium sulphate) and rock-salt are other examples of crystalline aqueous rocks.

The metamorphic rocks, being stratified rocks that have been changed by the action of heat and heated water, also show a crystalline texture. One peculiarity of this class of rocks, viz. the arrangement of the crystalline minerals forming them into layers so as to give them a foliated appearance, will shortly be noticed (see Gneiss, par. 149).

Putting the above in a tabular form, we may set it forth as below :—

Crystalline . .	Igneous—Granite, Basalt, &c.
	Aqueous—Some Limestones, Gypsum, Rock-salt.
	Metamorphic—Gneiss, Statuary Marble.
Non-crystalline or Fragmental	Igneous—Volcanic Ash.
	Aqueous—Sandstone, Clay, Conglomerate, Shale, Coal, &c.

115. **Further Classification of Rocks.**—A further subdivision and description of rocks will now be made. The stratified or aqueous rocks can be put into the following classes.

(*a*) Sedimentary or mechanically formed rocks.

(*b*) Organically formed rocks, or rocks formed out of the remains of animals and plants.

(*c*) Chemically formed rocks, which have been produced from material held in solution by water and afterwards precipitated.

116. (*a*) **Sedimentary Rocks.**—Streams, tides, and waves are continually wearing away portions of the earth's crust, and carrying it down to be deposited at a lower level when the water comes to rest. This mechanically suspended matter consists of what is called *sediment*, and the heavier particles are the first to fall down. Part of this sediment may consist of small rounded pebbles called gravel, part of sand, and part of very fine particles called clay or mud. Sedimentary rocks are those which have been formed out of sediments on the floors of lakes, in river-beds, or on the sea bottom, and have afterwards been raised above the surface. In process of time the materials are made to cohere by pressure and the infiltration of cementing substances.

These different kinds of sediment give rise to different sorts of sedimentary rocks—*conglomerate*, *sandstone*, and *clay*.

Conglomerate, or puddingstone, as it is called sometimes, consists of rounded water-worn pebbles, or masses of various rocks cemented together by some kind of mineral paste. This cementing material may be formed of carbonate of lime, silica, or oxide of iron. It is brought in solution by water, and as the water evaporates is deposited among the pebbles as a cement.

Loose rounded and water-worn pebbles about the size of a nut are called *gravel*, or *shingle*, and may consist of fragments from various rocks.

The pebbles forming a natural conglomerate may be derived from any kind of rock. If the pebbles are composed of quartz, or flint, we may call it a silicious conglomerate; if of limestone, a calcareous conglomerate. When the rock fragments that are cemented together have sharp angular corners, showing that they have not been subject to much water-action, the rock is called a *breccia*.

117. *Sandstone.*—This rock has already been described. The rounded water-worn grains of sand, which have been derived from the breaking up of rocks containing quartz, sometimes lie separate, and form large beds of loose sand. This loose sand consists mostly of silicious grains, sometimes with small particles of mica and fragments of shells.

On some sandy coasts, as the tides run down, the sand is left dry, and being caught up by the wind is blown inland, so that in the course of years a ridge of hills, called *sand-dunes*, is formed. When the loose sand is, however, left undisturbed at the bottom of the sea or of a lake, in process of time it becomes consolidated by pressure and by cementing material. This cementing material varies as in the case of conglomerate, and hence we have *calcareous* sandstones and *ferruginous* (Lat. *ferrum*, iron), according as the cementing material is calcium carbonate or oxide of iron. The oxide of iron usually colours the sandstone yellow or red. Sandstone is much used for building purposes, often forming window-sills, lintels, and doorposts. Some kinds show a tendency to split into slabs parallel to the stratification, and are then much used for flagstones. When the silicious particles are rather large and angular the sandstone is called a *gritstone*. Such gritstones are often used for grindstones and millstones.

Sandstones are spoken of as arenaceous rocks (Lat. *arena*, sand).

118. **Clay.**—Clay consists of very fine particles which adhere together,

and form a substance which can be easily moulded into various shapes. Hence it is said to be plastic. It is the last result of the waste of rocks by water and other natural agents. It is chiefly composed of silicate of alumina with water ($Al_2O_3,2SiO_2,2H_2O$). It is derived mainly from the decomposition of felspar and other aluminous silicates by the action of the weather, the potash and the soda being washed away, especially by water containing carbonic acid in solution. It is generally found in valleys and lowlands, and has the important property of being impervious to water. Hence where there is a series of beds of porous rocks, such as sand, gravel, or chalk, resting on clay, the water sinks through these until it reaches the clay. It then accumulates until it can find an outlet. Clay is often mixed with various impurities, which impart to it a brown, red, or blue colour. Kaolin, or china clay, is the name given to a pure kind much used for the manufacture of porcelain. Common clay is much used for making bricks.

Rocks containing much clay are called *argillaceous* (Lat. *argilla,* clay).

When mixed with water, clay forms *mud,* though the word mud is applied to any finely divided mineral matter.

119. *Shale* is clay or mud that has become hardened, and which splits into thin plates or laminæ, parallel to the stratification. Such rocks are said to be laminated, and thus show that they have been gradually deposited under water.

Shales are often dark-coloured through vegetable matter, and frequently have the impression of ferns, &c., distinctly marked. All clayey rocks give out an earthy smell when breathed upon.

120. **Loam** is the name given to a mixture of *clay* and *marl,* which coheres less than clay, and which is pervious to water.

121. **Marl** is a soft and friable (easily powdered) mixture of clay and calcareous matter, often used by farmers for improving soils poor in lime.

122. (*b*) **Organic Rocks.**—The second division of the stratified or aqueous rocks includes those rocks that are mainly formed by the agency of animal or vegetable life. The material forming these masses has already been described under the head Organic Rock Material.

This material embraced chalk, limestone, coral, peat, and coal. We shall now speak of the arrangement of some of this material as it occurs in masses sufficiently large to be called rocks.

Enough has been said about the way in which chalk beds have been formed at the bottom of the sea by the accumulation of the calcareous shells of the minute Foraminifera and other lowly organisms, and also of the beds of calcareous mud that are now being formed on the ocean floor, as is shown by deep-sea dredgings. Chalk forms an important division of the series of rocks, and in some parts of England is more than 1,000 feet thick. These beds of chalk are chiefly found in the south and west of our country. Nodules of flint occur frequently in the chalk, and this is accounted for by the belief that this flint has been derived from the hard parts of silicious organisms, as sponges, &c., and by the concretion or growth of other silica round these as a nucleus. Sea water has always a certain amount of silica in solution. Hence flint may be included under the list of organically derived rocks.

123. **Limestone.**—The composition and structure of this rock has already been described when speaking of the minerals that form rocks, and it has been shown that it belongs to the class of organically formed rocks because it consists of the

fossil remains of creatures having calcareous shells, and that these remains have accumulated under water to form beds or strata (see par. 105).

The structure of limestone varies greatly, some limestone consisting of the minute shells of Foraminifera, and some consisting of the stems of encrinites and other similar organisms. In some cases the limestone has been so largely altered that no traces of organic origin can be detected. Such limestone has often a bluish colour.

124. *Marble* is simply limestone that has become so hard that it will polish.

Beds of limestone occur in many of the geological formations, and are often of great thickness.

125. **Coral Reefs.**—The secretion of coral from the sea water by the coral polyp has been described in a previous paragraph (107). It remains for us to describe the masses of rock forming coral land, and the mode in which these masses have been built up.

Coral rocks are found as ridges or banks in the sea, and are therefore called coral *reefs*. Coral reefs are divided into three classes :—

(1) *Fringing reefs*, which form a ridge of rock at a short distance from some mainland or island.

(2) *Barrier reefs*, which are banks running nearly parallel to the coast at a greater distance than fringing reefs, so as to leave a broad channel.

(3) *Atolls*, which are ring-shaped belts of coral reef, enclosing a lagoon of shallow water, and forming an island.

It has already been stated that the reef-building corals require for their existence clear water not below 68° F. of temperature, so that where the water is muddy, as near the mouths of large rivers, or where cold currents or other causes bring the water below the above temperature, there the reef-building polyps cannot exist. Nor can they exist but in shallow water, for they seem to die at a greater depth than 100 feet. They flourish best where the water is in constant motion and where it is clear, as at the outer edge of the reef. Hence the range of coral reefs and islands is limited by these conditions to a district about 25° on each side of the equator. The Bermuda Islands, which lie in the course of the Gulf Stream, form the northernmost point at which reef-building corals are found, but the Atlantic Ocean has not many of these rocks. Some are found among the West Indies and Cape Verde Islands, and off the coast of Florida. In the

Pacific there is a belt of coral rocks, both islands and reefs, stretching from the Low Archipelago to the Caroline Islands. There is also in the Indian Ocean a band of coral islands between Madagascar and India, including the Maldive Islands and the Laccadive Islands. Numerous reefs also occur in the Red Sea (see map 2). The largest barrier reefs are those off the island of New Caledonia and off the north-east coast of Australia. The Australian barrier reef is nearly 1,200 miles long, and usually about 120 miles from the shore. At its outer edge it rises out of the sea from a depth of 1,800 feet.

126. **How Reefs and Islands are formed.**—*Sea Depths near Coral Reefs.*—The outer edge of a coral reef dips gradually for a short distance, and then the sea rapidly becomes very deep.

As the coral polyps cannot exist above the surface of the water, and as they cannot live at a greater depth than about 100 feet, it is plain that the coral reef cannot be carried below a depth of 100 feet nor raised above the level of low water by the animals alone.

The explanation of the appearance of the reef above the water is as follows. As the mass of rock reaches the surface of the sea the waves dash against its outer margin, break off pieces of the coral, and pile up these broken masses, so that the edge of the reef appears above the water. Dana says that 'after the growing corals and the accumulating débris reach low-tide level the polyps mostly die ; but the waves continue to pile up on the reef, sand, pebbles, and broken masses of coral, some of the masses being two or three hundred cubic feet in size, and a field of rough rocks begins to appear above the waves. Next a beach is formed ; and the bank of coral débris, now mostly above the salt water, becomes planted by the waves with sea-borne seeds. Trailing shrubs spring up ; and afterwards, as the soil deepens, palms and other trees rise into forests, and the coral island or atoll comes forth finished.'

127. *Darwin's Hypothesis.*—To account for the way in which coral reefs so often rise from great depths Mr. Darwin offered the following explanation. According to him each atoll began as a fringing reef, then became a barrier reef, and at last appeared as a ring-shaped island with a central lagoon. For since the reef-builders cannot live below 100 feet, the foundation of the reef could not have been laid at a greater depth. Such shallow waters are only found near the shores, and hence the coral rock was first formed as a fringing reef. If a fringing reef be thus formed round an island, and then the island gradually sink deeper into the sea, while the corals continue to grow upwards, the fringing reef will be changed into a barrier reef. The island will have become smaller, and the water between it and the reef wider. Another gradual subsidence of the island, while the reef-builders keep pace with the sinking, will at last cause the central peak of the island to disappear, and the reef will rise in the shape of a more or less broken ring, with water in the centre. It has become a ring-shaped reef or atoll. Hence barrier reefs and atolls are, according to Mr. Darwin, due to subsidence of land, though a fringing reef may be built on a stationary or even slowly rising sea-floor.

The following diagram illustrates Mr. Darwin's theory. S is the original land, at the edge of which the coral polyps begin to build so as to form the fringing reef C C. As the land sinks further the coral polyps keep pace with it, and in time the barrier reef C′ C′ is seen. Further subsidence causes the centre of the original land to sink beneath the surface, and the ring of coral rising above the surface forms an atoll with a central lagoon.

As the corals thrive best in the full play of the surf, owing to the freshness of the water there and the better supply of food, it is found that in the inner margin of the reef the animals die off. Hence it happens that in the central lagoon not only is there no increase of rock, but the solvent action of the sea water causes part of the rock to disappear, and the lagoon may thus become deeper and wider.

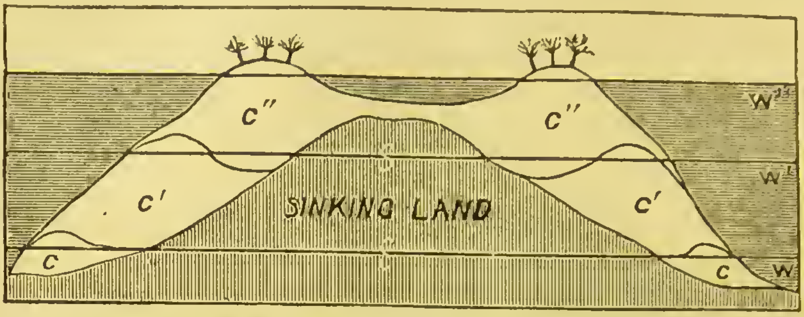


FIG. 33.—Diagram showing Mode of Growth of Coral Reefs and Atoll, according to Darwin.

128. Mr. Murray, one of the naturalists accompanying the *Challenger* in its celebrated voyage of exploration, explains the formation of coral reefs in a different way; and his explanation is supported by others. He found that many of the little islands surrounded by coral reefs show traces of volcanic origin, and not traces of subsidence. Mr. Murray therefore believes that the rocks have been built up from the tops and slopes of submerged and partly submerged volcanic mountains. Imagine a submarine volcanic peak with the edges of its crater little more than a hundred feet below the surface. Even if the reef-building corals could not begin to

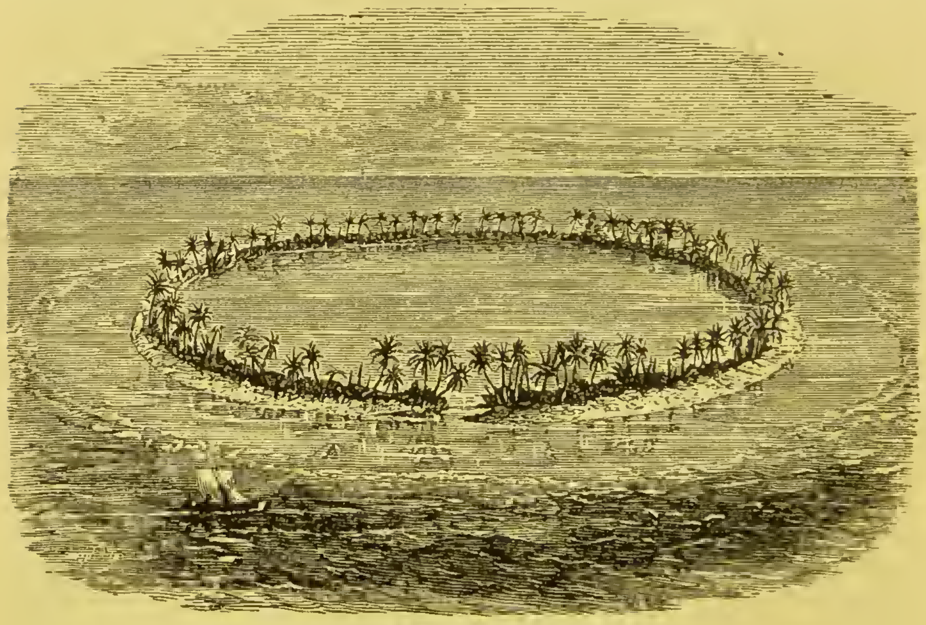


FIG. 34.—An Atoll, showing Central Lagoon.

build at such a depth, it would in time be raised higher by the accumulation of the solid parts of various shell-fish, and thus brought within the limits of the coral polyps. It is evident that reefs growing upwards from such a submarine peak would assume the form of an atoll. Where a volcanic cone still projected above the sea, Mr. Murray believes that a reef might arise and grow outwards without any subsidence of the land on which it rests. Or a reef might begin to rise on a shoal formed by ocean currents. As the reef grows chiefly on its outward edge where the corals flourish best, and as the animals die and the rock is dissolved by the warm waters in the inner lagoon, every fringing reef thus tends in course of time to become a barrier reef. The sea water of the lagoon is charged with carbonic acid derived from the decaying polyps, and this increases its power of dissolving the calcareous rock. The barrier reef grows seaward by building on the new foundations formed by its own broken and submerged fragments, and the lagoon interval between the front of the reef and the shore becomes widened through the solvent action of the water on the rocks where the corals have ceased to live. Hence, according to this theory, the width of the lagoon ought to be, in some degree, a measure of the antiquity of the reef.

Probably the explanation given by Mr. Darwin accounts for the formation of some of the atolls and reefs, while that of Mr. Murray explains that of others. The question, however, is still in dispute.

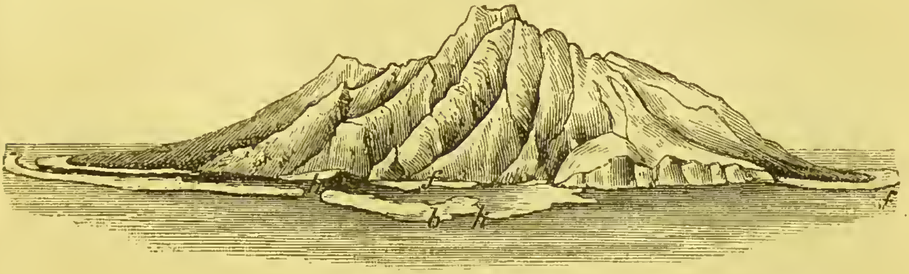


FIG. 35.—Rocky Island bordered by Coral Reefs (after Dana). *f*, fringing reef ; *b*, barrier reef ; *h h*, openings in the reef.

129. **Peat** is found in the bogs and marshes of the British islands ; and these damp places are abundant in the west of Ireland, in the fen district of England, and in certain places in Scotland. It consists of a brownish-black compressed mass of partially decomposed vegetable matter. In this change the woody fibre of the marsh-loving plants has lost a part of its gases ; but, unlike coal, it still contains 25 to 30 per cent. of oxygen, and has only about 50 per cent. of carbon (see Table, par. 104).

At the surface there grows a green living moss called ' bog moss,' with other marsh-loving plants. A few inches below are found the brown rotting fibres of the dead plants, and still further the mass becomes denser and darker. At a depth of about 25 feet we often find a compact black substance which can be cut into blocks. These are piled into small stacks to dry, and are afterwards used by the peasantry for fuel. At the bottom of a peat moss there is often found a bed of clay or marl, containing fresh-water shells, and these show that the peat moss has been formed on the site of an old lake which has afterwards been turned into a swamp or marsh. In other cases a forest has been converted into a swamp, and then the bog mosses and other plants began to grow in abundance, and in time they increased and spread themselves so much that all the fallen trees were buried in the decaying moss.

130. **Coal.**—The table already given in par. 104 shows that coal differs from peat in containing a greater proportion of carbon and a less proportion of oxygen and nitrogen. Though both are of vegetable origin, coal also differs from peat in the mode of its occurrence, and in the kind of plants out of which it has been formed. Coal is found buried in the crust of the earth in *beds* or *seams*, varying in thickness from a few inches to several yards. As it is arranged in layers, and as by examining a large piece we can find one particular direction in which it will split most easily, it is plain that coal is a stratified rock. Every bed of coal is found to rest upon a bed of clay, usually hardened into shale, and this 'under-clay,' as it is called, is penetrated by numerous roots shooting down into it. Above the coal seam we find another bed of clay or sand, which is called the 'roof' of the coal, and in which are found numerous stems and branches of plants. Further in the coal itself the impressions of ferns and other plants are sometimes visible; and if a very thin section be examined under the microscope, thousands of spore-cases or seed-vessels may often be seen. Putting all these facts together, it becomes quite certain that coal is formed out of the remains of old vegetation; that the plants from which it has been formed actually grew on the spot where the coal is now found; that the 'under-clay' is the old soil in which these plants grew; and that the 'roof' represents the accumulation of sediment deposited on the vegetable remains after the old land surface had sunk beneath water.

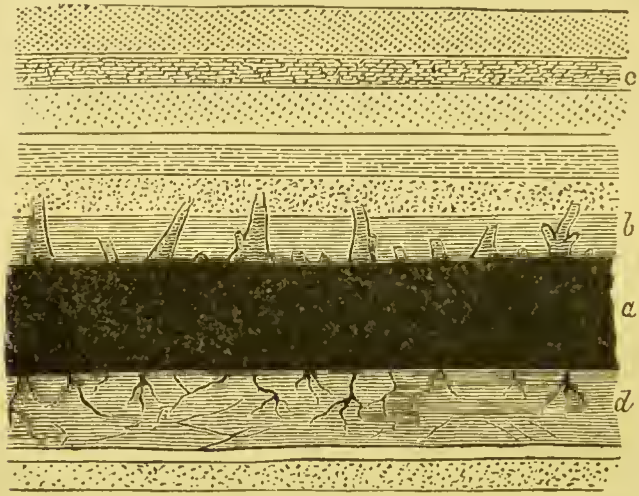


Fig. 36.—Section showing Coal Seam. *a*, coal seam; *d*, under-clay; *b*, *c*, shale and sandstone forming roof.

It has been found that the vegetation out of which coal has been formed indicates a warm moist climate and a low marshy district. Numerous ferns, some of very large size, were found; and huge reed-like plants having a jointed fluted stem, and known as calamites, were abundant. An enormous number of plants related to our club-mosses, but reaching the size of ordinary trees, flourished (see Frontispiece). Of these, the lepidodendron and the sigillaria are noteworthy. The stems of the lepidodendron were marked with lozenge-shaped scars; the sigillaria had cylindrical fluted stems of great height, marked longitudinally with leaf-scars, and having long spirally pitted roots called stigmaria. Sigillaria was the upright stem of the plant, and stigmaria the root of it. All these belonged to the class of flowerless plants; but in addition to these a number of true trees related to the pine and yew have been noticed.

Coal, then, may be regarded as composed of the remains of the stems, branches, leaves, and seeds of ferns, calamites lepidodendra, sigillaria, and pines. Numerous generations of these plants lived and died, so as to heap up a great thickness of vegetable remains, and in time the surface of the land where this accumulation was taking place sank beneath the sea. Most of the trees were overthrown, but others remained standing until the whole was buried beneath the sand and clay deposited around. This accounts for the 'roof' of the coal seam so often containing the upright stems of trees. The vegetable matter thus entombed remained for thousands of years, undergoing changes due to the great pressure upon it and the chemical actions going on within it. After a long period this old land was raised again a little above the level of the sea by deposits of mud, &c., and another rank and luxuriant vegetation began to grow. The land sank once more, sand and mud again covered the vegetation, and a second coal-bed was formed above the first. By repeated depressions it is easy to see that several coal seams might be formed in succession over the same area.

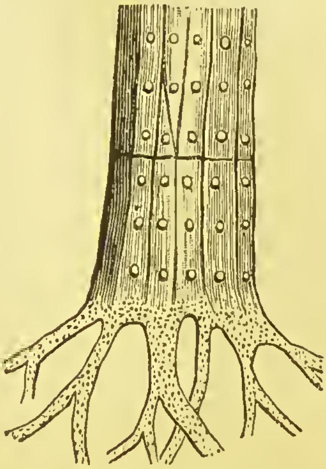


FIG. 37.—Sigillaria Stem with Stigmaria Roots.

131. (*c*) **Chemically formed Rocks.**—This class includes those rocks that have been formed by the chemical process called precipitation. The material of which they are composed has been at one time in solution in water, and as the water evaporated the matter was deposited. In this way considerable masses have been formed in some districts, though when compared as to bulk with the other rocks of the earth's crust these rocks are insignificant.

The water of rivers that have flowed over limestone rocks carries down to lakes or seas a quantity of calcium carbonate in solution, and in speaking of chalk and coral we saw how by the agency of animals this has been extracted to form again other beds of limestone, known as chalk beds and coral reefs. But the waters of springs contain other substances, such as sodium chloride and calcium sulphate, and these substances are also found as rocks. In this case the rock could not have been formed by the agency of animals, because no animals extract these substances from water.

132. **Petrifying Springs, Limestone Caverns, Stalactites, Stalagmites, and Travertine.**—It must be remembered that pure water does not dissolve calcium carbonate (carbonate of lime), but only water containing carbon dioxide in solution. Rain-water always contains a certain amount of carbon dioxide dissolved out of the air, and this quantity is sometimes greatly increased as the water passes through decomposing organic material in the rocks. Besides, during its underground course the water is often under great pressure, and it can then hold more carbon dioxide and dissolves more carbonate of lime than at the surface. As the air is reached some of the carbon dioxide escapes, and part of the carbonate of lime is precipitated. Such springs, on reaching the surface, deposit a film of carbonate of lime on everything around, and if birds' nests or bits of wool be left in the spray from such a spring they soon acquire a coating of this substance. Popularly, springs like this are called *petrifying* springs (Lat. *petra*, a rock or stone). But it is a mistake to suppose that the substance has been turned into stone ; it has only received an outer covering or incrustation of carbonate of lime. But before such springs come to the surface much work has been done by the water. Great cavities are frequently formed in limestone rocks by the solvent power of the water thus charged with carbon dioxide. Such caverns are frequent in the limestone districts of Derbyshire and other parts. Not only are caverns thus formed by masses of rock being dissolved away, but curious effects are sometimes wrought within these caverns. As the water hangs on the roof, some of it evaporates, and thus deposits a portion of the limestone held in solution. In process of time there is formed in this way a pendant mass of calcium carbonate like an icicle. This is called a *Stalactite.* Some of the water dropping on the floor gives up, on further evaporation, more of the limestone in solution, and thus a projection rises on the floor of the cavern like the one on the roof. This is called a *Stalagmite.* At times the stalactite from the roof and the stalagmite from the floor meet and form a continuous column, as is shown in fig. 38. *Travertine*, or calcareous tufa, is a porous friable limestone deposited at the surface, often on a hill-side, by the waters of a calcareous spring.

133. **Salt Lakes.**—Beds of rock-salt (sodium chloride, NaCl) several hundred feet in thickness are found in Cheshire, Bohemia, and other places, and these beds must have been formed by the evaporation of bodies of water. The Dead Sea and the Great Salt Lake of Utah are examples of great enclosed salt lakes, which were originally fresh, as is shown by the freshwater organisms found on their shores. The water of these lakes is carried off by evaporation as fast as, or faster than, it is brought in, and hence the amount of dissolved matter increases. The valley of the Dead Sea is the lowest on the earth, the surface of the water being 1,298 feet below the level of the Mediterranean. Its waters now contain 24 per cent. of salts by weight, or nearly seven times the proportion in ordinary sea-water. The Caspian and Aral seas were originally salt, being situated in

a depression which is believed to have once communicated with the Arctic Ocean, subsequent elevation of the land having cut off the connection. Deposits of rock-salt are now forming on the beds of these lakes.

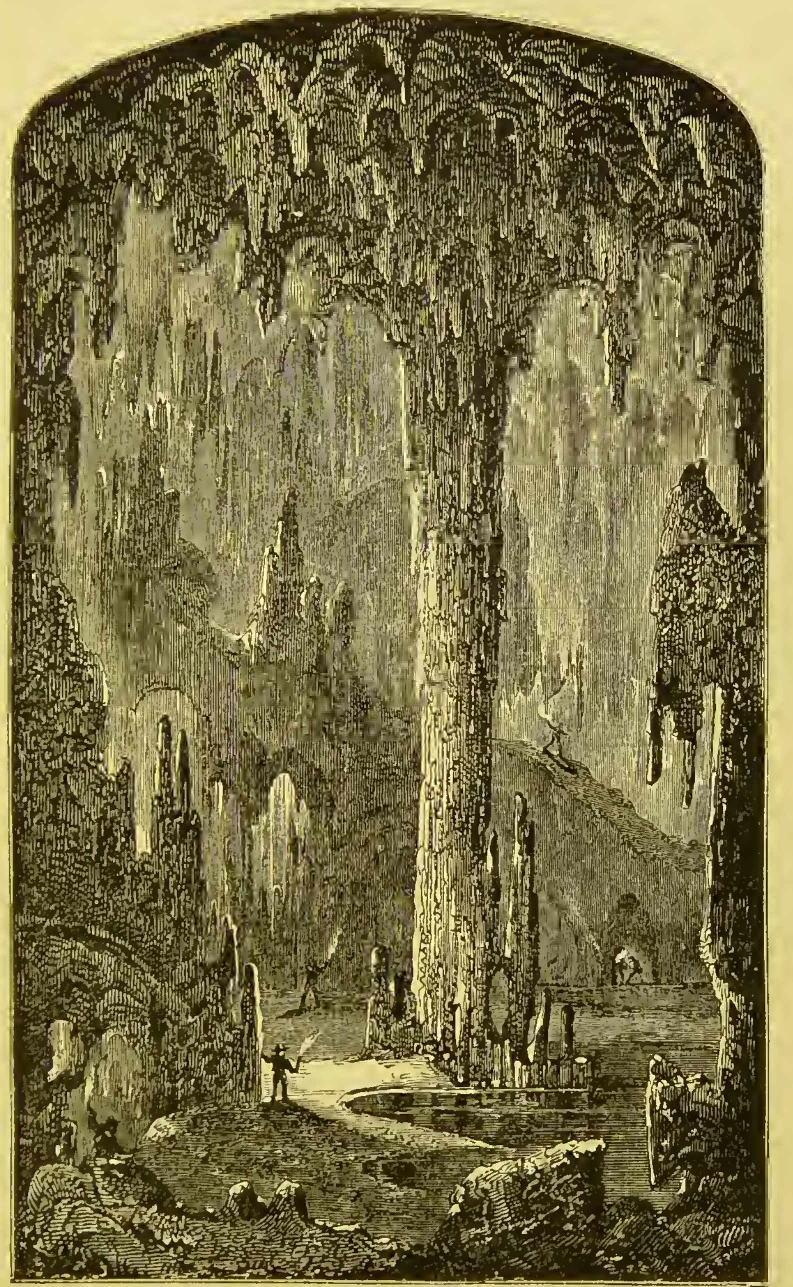


Fig. 38.—Entrance to the Cave of Adelsberg (in Carniola, 22 miles N. of Trieste). Stalactites are seen hanging from the roof, stalagmites rising from the floor.

134. **Gypsum**, or calcium sulphate, is another substance frequently found in beds that have been deposited after the water that has held it in

solution has evaporated. It is sometimes associated with a similar deposit of dolomite, or magnesian limestone.

135. **Sinter** is a light porous variety of silica deposited in the neighbourhood of geysers and hot springs. Silica is quite insoluble in ordinary water, but hot water charged with soda can dissolve it, and minute algæ secrete portions of this dissolved silica, thus aiding to form the deposit on their death. See Geyser, par. 245.

136. **Classification of Igneous Rocks.**—The general characters of these rocks have already been described in a previous paragraph. The unstratified or igneous rocks are often divided into two groups, according to the circumstances under which they are supposed to have solidified from a state of fusion. These two groups are known as *volcanic* rocks and *plutonic* rocks. The volcanic rocks are those which have been ejected from volcanoes or have welled out through fissures in the crust. They have consequently cooled in contact with the air. The plutonic rocks have been formed beneath the surface when subject to great pressure. As they have cooled more slowly than those sent out to the surface their crystals have been able to form more clearly. They are generally intrusive, having been forced through or between strata already formed. They occur in irregular masses, and often fill up huge fissures as wall-like masses called *dykes*. A dyke is thus a vertical wall of igneous rock that has been forced in a molten state into a fissure in the strata and has there solidified. It is plain that the two kinds of rocks are not marked off from one another by any sharp division, for what is a volcanic rock at the surface would often become a plutonic rock on being traced downwards. There is, however, often a difference in structure, as the plutonic rocks are usually

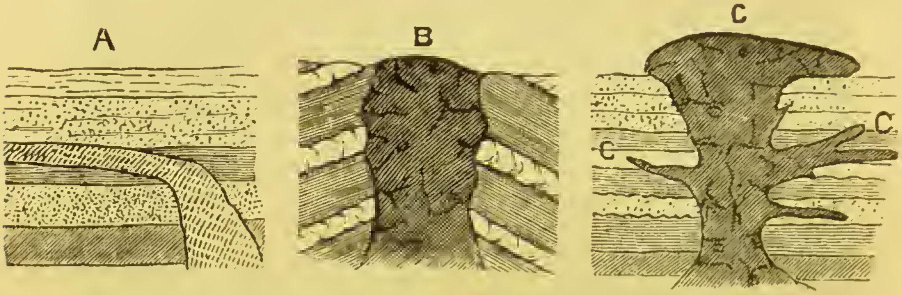


FIG. 39.—Intrusive Igneous Rocks. A, Interstratified Sheet; B, Dyke; C, Veins and Boss.

more distinctly and coarsely crystalline in structure, and do not show the glassy and spongy characters often exhibited by lava, having consolidated at great depths.

All the igneous rocks are mainly composed of silicates—that is, they contain silica (SiO_2) united with the oxides of such metals as aluminium, calcium, magnesium, iron, potassium, and sodium.

137. **Volcanic Rocks.**—The volcanic rocks are themselves of two kinds, *volcanic ashes* and *lavas*. Volcanic ashes consist of the fragments and dust driven out from a volcano. These fragmentary materials vary in size from large blocks to the finest dust, and by their accumulation round the vent build up the volcanic cone. The finer and lighter portions, however, are carried to a great height by the vapour and gases from the vent, and are often borne away hundreds of miles by the wind. The finest volcanic ashes are mostly the broken films of bubbles of lava blown into a fine state by the explosion of vapour and gases imprisoned in them; while the cinder-like fragments called *scoriæ* are larger pieces of lava sent up from the lava column in the pipe of the volcano. In time these ashes become consolidated into a porous rock, called volcanic tuff. This is often caused by the ashes becoming mixed with water, which changes them into a kind of mud that sets like mortar. The city of Herculaneum was buried by such volcanic tuff that came from the eruption of Vesuvius in 79 A.D. The word 'ash' applied to these fragmentary materials only means that they are in a finely divided state, and not as in ordinary language the incombustible mineral residue found in fuel.

138. **Lava.**—Lava is the name given to the more or less molten rock which rises up the tube or pipe of a volcano and flows out over the edge of the crater at the top, or forces its way through fissures in the side. Some lavas flow quickly, like molten iron, while others are less liquid, and move very slowly. In some cases the lava stream scarcely reaches the bottom of the mountain, but in other cases it runs many miles. The upper surface of a lava stream cools quickly, and has generally a cindery or *scoriaceous* appearance. It is full of small holes or cells formed by the escape of steam from its surface, so that it has a spongy texture. This gives it what is called a vesicular or cellular structure (Lat. *vesicula*, a small bladder). The lower portion of the lava stream is also cooled by contact with the rock beneath. In the middle, however, the lava stream cools very slowly, and acquires a more solid and glassy structure. The interior of a lava stream sometimes retains a great heat for several years.

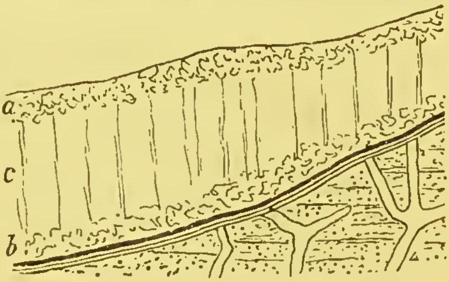


FIG. 40.—Section of Lava Stream. *a* and *b*, scoriaceous surfaces; *c*, solid interior.

Instead of flowing out into the air, lava may be forcibly driven into the surrounding strata, where it solidifies, either in an upright wall of rock forming a *dyke*, or in a horizontal layer between the sedimentary rocks, when it is said to be interstratified. These intrusive igneous rocks may send out offshoots in various directions. It must be noted that a lava stream that has been sent out into the air may afterwards become covered with sediment, and thus become interstratified. Such *contemporaneous lava*, as it is called, will have its upper surface cindery, and can be thus distinguished from an intrusive sheet which has not such a cindery upper surface, and which causes the rock lying *above* as well as below to be more or less baked and altered.

In some districts the lava does not appear to have flowed out from a central pipe in a volcano, but to have been sent forth through numerous fissures in the crust in such quantity as to flood thousands of square miles at once. In the western part of North America there is a vast plateau of lava. in some parts over 3,000 feet in thickness. There are other such beds in Western Europe, the north of Ireland, Iceland, and Norway. The name trap is sometimes given to the old step-like lavas which have flowed in successive horizontal sheets, and which form at their edges an appearance like stairs (*trappa* is a Swedish word for *stair*).

139. **Varieties of Lava Rock.**—The chief kinds of lava are trachyte, obsidian, pumice, and basalt.

Trachyte is a lava composed mainly of potash felspar, with other silicates. It is usually of a grey colour, and feels rough and prickly to the fingers. Quartz-trachyte or *Rhyolite* is the lava form of granite.

Obsidian, or volcanic glass, is a variety of lava, rich in silica, and very like ordinary coarse bottle-glass in appearance.

Pumice is an ashy, grey, rough, porous variety of rock formed from the glassy lavas. It is, in fact, the froth or scum of such vitreous lava, and is full of small elongated cavities or cells, formed by escaping steam and gases. It occurs both in the form of ejected masses and also on the surface. It floats on water, owing to these cavities being now filled with air, so that it thus becomes lighter than water bulk for bulk. If the pumice be powdered, it quickly sinks in water. The pumice from a volcano may find its way into the sea, where it floats for a long time, until the thin glassy divisions between the air chambers are broken down. It then becomes water-logged, and finally sinks to the bottom. Pumice-stone is much used by painters to render the surface of boards, &c., smooth. The pupil may probably obtain a specimen from one of these workmen.

Basalt is a lava of a dark colour, dense and heavy, and breaking with a conchoidal or shell-like fracture. It consists of a variety of felspar and of a mineral called augite. *Dolerite* is a variety of basalt coarsely crystalline. The basalt rocks are found both as intrusive masses and as sheets that have been poured out on the surface. Many of these lava sheets of basalt in slowly cooling and solidifying acquired a columnar structure, the columns often having a more or less hexagonal shape, though the number of sides varies (see fig. 41). Interesting examples of these columnar basalts occur at Fingal's Cave in the island of Staffa, and at the Giant's Causeway in the north of Ireland.

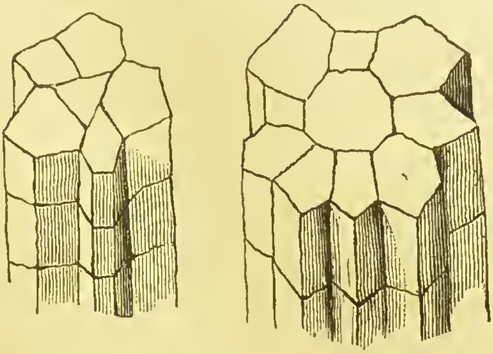


Fig. 41.—Columnar Structure of Basalt.

140. **Plutonic Rocks.**—The most important of this division are *granite* and *felstone.* It has already been shown that granite is a granular crystalline mixture of quartz, felspar, and mica (see par. 88). The separate constituents can be distinguished by the eye, though the minerals have seldom had room to assume a perfect shape. In some specimens the crystals of felspar are very large and distinct, and the rock is then called *porphyritic granite.* Such granite is found on Dartmoor. The granite from Peterhead is of a reddish colour, that from Aberdeen grey. The greater part of the Grampians, the Cumbrian group, and the mountains of Devon and Cornwall consist of granite. *Syenite* is a granitic rock in which the mica is

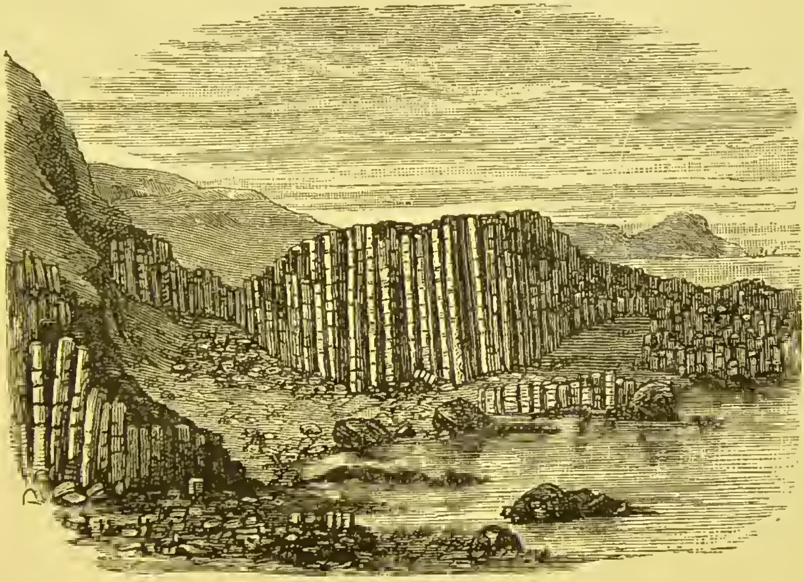


Fig. 42.—Giant's Causeway, Antrim: Basaltic Columns.

replaced by hornblende, and in which free quartz is absent, or only present in small quantity. Granite not only occurs in large eruptive masses forming the central parts of mountain chains, but also in smaller dykes, veins, and bosses. When granites are weathered—that is, exposed to the action of frost, heat, rain, and rain-water containing carbonic acid—the felspar crystals are slowly decomposed, and the rock crumbles away. The soluble potash and soda silicates in the felspar are washed away, but the silicate of alumina forms a white powder called kaolin, or china clay. The quartz breaks up into small grains, and the mica into thin flakes, and these grains form the sand found on the beds of rivers, and on the sea-shore, becoming more rounded and reduced the longer they are submitted to the action of the water. In time, and under suitable conditions, this sand may become consolidated into a sedimentary rock, and the sandstone thus formed may itself suffer disintegration (breaking up) and re-formation many times.

141. **Felstone,** or felsite, is a close-grained rock composed of an intimate mixture of felspar and quartz. It is very compact, and usually of a dull green or purplish colour. It is found in some of the mountains of North Wales, and is quarried for making paving sets.

142. **Acidic and Basic Rocks.**—The above division of the igneous rocks, due to their mode of formation, is perhaps the most useful for the beginner; but there is another mode of classifying them, based on their chemical composition, which is of some importance. Since silica acts as a weak acid, those igneous rocks in which silica exists in large proportion (66 to 80 per cent.) are called acidic rocks (granites, rhyolites, &c.); the igneous rocks that contain a relatively small proportion of silica (45 to 55 per cent.) and a large proportion of metallic oxides, are called basic rocks (basalt, dolerite, &c.). There is an intermediate class, where the proportion of silica is less than in the acidic rocks but more than in the basic ones. The acid or highly silicated rocks are often of a light colour, and being poor in lime, magnesia, and iron, are difficult of fusion. The basic or poorly silicated rocks are of a darker colour, of a higher specific gravity, and are richer in lime, magnesia, and iron than the acid rocks, and have no quartz or *free* silica. The following table summarises the information already given regarding the classification and composition of igneous rocks.

143. *Classification of Igneous or Unstratified Rocks.*

Division	Mineral Composition	Plutonic Varieties	Volcanic Varieties
Acidic Rocks	Quartz, Felspar, Mica	Granite	Rhyolite, Obsidian
Basic Rocks	Felspar and Hornblende, or Augite, with oxides of iron, lime, and magnesia	Dolerite, Gabbro	Basalt
Intermediate Rocks	Felspar and Hornblende	Syenite	Trachyte

144. **Metamorphic Rocks.**—It now remains for us to describe two or three members of the class of transformed or altered sedi-

mentary rocks, those in which the structure has been rendered more or less crystalline, and in some of which new chemical combinations have been brought about. This metamorphism or change is often observed in the neighbourhood of dykes and other intrusive igneous masses. The following are examples of this class.

145. *Crystalline Limestone*, or statuary marble, is only limestone that has been altered by heat so as to give it a granular texture like loaf sugar. Some marbles are coloured by mineral matter, and all are capable of being polished.

146. *Quartzite* is sandstone that has been hardened by partial fusion, so that the grains of sand have run together.

147. *Slate* is shale that has been hardened and otherwise changed by intense lateral pressure, and is composed mainly of aluminium silicate. In speaking of shale we described it as a hardened clay that splits into laminæ or thin leaves parallel to the layers of deposition. This shale was formed by film after film of fine sediment having been placed one on another, and this compacted by pressure from above, so that the films or laminæ acquired a tendency to separate one from another like the leaves of a book. The shale has undergone further alteration by great lateral pressure, causing it to split or cleave into leaves in a direction different from the bedding; and such altered shale is called slate.

148. **Cleavage**, or slaty cleavage, is the name given to the tendency found in some rocks to split into layers or flakes more or less perpendicular to the original layers of deposition; while *lamination* (Lat. *lamina*, a leaf) is the name given to the arrangement in thin layers parallel to the bedding. Shale has a laminated structure, but slate shows cleavage.

149. **Gneiss.**—Gneiss is composed of the same minerals as granite, viz. quartz, felspar, and mica, but the minerals are arranged in layers or bands. Rocks in which the minerals are arranged in layers are said to be *foliated*, and this foliated arrangement of the minerals is the great peculiarity of gneiss. It occurs among the oldest known rocks of the earth's crust. Here is a drawing of a piece of gneiss, showing the foliated arrangement of the component minerals. The light layers consist of granular felspar, with here and there a little mica and quartz. The dark bands indicate layers of black mica intermingled with grains of grey quartz. The rock will split most easily along the dark layers.

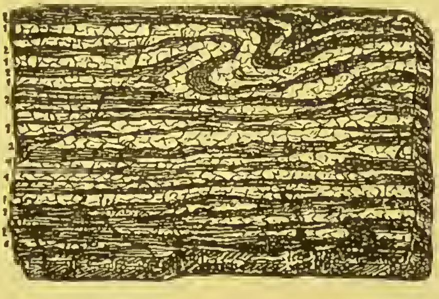


FIG. 43.—Gneiss.

Mica-schist is a metamorphic rock consisting of irregular wavy layers of the two minerals quartz and mica.

150. **Soil—its Formation and Composition.**—It is only on mountainous hill-sides, steep rocks, and water-washed shores that the actual bare rock is seen at the surface. In other places the upper layer of the solid land consists of a thin covering of loose particles of decomposed rocks, which furnish a reservoir for the solid and liquid materials that serve to nourish

plants, and also contain the decaying remains of these plants after their death. This upper layer is usually called soil or vegetable earth. Soil, then, is the superficial covering of the earth in which vegetation grows, and is formed of the disintegrated or broken-up particles of rocks, mixed with decaying vegetable and animal matter. The chief agents that bring about this disintegration and decomposition are rain, changes of temperature, frost, the atmosphere, and the roots of plants. The rain softens and in some cases decomposes the minerals forming the rock, for in falling through the atmosphere it dissolves oxygen and carbonic acid, and these assist in the wearing away of the rocks. The oxygen oxidises some of the rock substances, causing them to fall into powder, while the carbonic acid in solution assists in dissolving some of the more soluble ingredients. Rocks containing iron have frequently a reddish tinge, due to the iron oxide. The heat of the sun during the day expands the rocks, and the rapid radiation of the heat after sunset soon causes the stone to become cold and contract. The effect of these alternate expansions and contractions is to crack the rock and loosen the particles on the surface. This is further assisted by the rocks at one time getting soaked with water and then rapidly dried. Frost, too, is a very active agent in this process of splitting rocks. The water that falls on the ground soaks through the soil and into the pores and crevices of the rocks. As the air falls below freezing-point this water is turned into ice. Water in being frozen expands with great force, and this expansion pushes aside particles and masses of rocks, so that every winter this work of destruction by frost goes on extensively, and may easily be seen on examining the face of an exposed cliff.

These various actions are often spoken of as the 'weathering' of the rocks, for they are mainly due to the changes that take place in the atmosphere. They are also spoken of as 'sub-aërial' denudation, as they take place *beneath* the surrounding air, in contradistinction to what takes place at the bottom of water. Vegetation partly prevents the action of these weathering influences by forming a protective covering over them, and partly assists by keeping the rocks wet, and by sending roots which force their way through cracks and joints, and thus loosen them. Animals that live in the ground also aid in the work. Even the despised earthworms bring to the surface large quantities of the finer parts of the soil which they have swallowed and passed through their bodies. Most of the soil formed in the way thus described at last finds its way into lakes or seas, for even after it has been washed down the mountain slopes into the valleys and plains, though it may rest there for hundreds of years, it is eventually carried away into rivers, and thence to the sea. The thickness of the soil varies from one or two inches to several feet. It is thinnest on hill-sides, where it is washed down by the rain or blown away by the wind ; and it is thickest in flat districts, where the water carries away but little. All kinds of rocks are subject to these actions—the stratified rocks that once formed the floors of seas and lakes, and the igneous rocks that have been pushed up to the surface. The character of the soil, therefore, depends on the kind of rocks from which it has been formed. There are clayey or heavy soils, that form mud in wet weather, and clods in dry weather ; sandy or light soils, that never clod, but allow the water to pass quickly through them ; calcareous soils, which contain a good proportion of calcium carbonate, &c. A good soil, however, for agricultural purposes consists of a due admixture of these different kinds with a certain amount of decaying animal and vegetable matter.

Usually the rocks from which a soil is derived will be found on digging down for a few feet, though in some cases the materials may have been derived from distant rocks. Here is a section which shows how the rock passes upwards into soil. Such a section may be frequently found by digging a hole in a field, or looking at the exposed edge of some river bank in the country. At *a* we have a thin layer of soil in which the grass grows, and composed of the materials already mentioned and described further below. At *b* we come to broken-up crumbling stones, which increase in size as we descend. This layer is called the *subsoil*, and often contains a few roots from the larger plants. At *c* we find the solid rock of limestone, divided into blocks by natural divisions called *joints.*

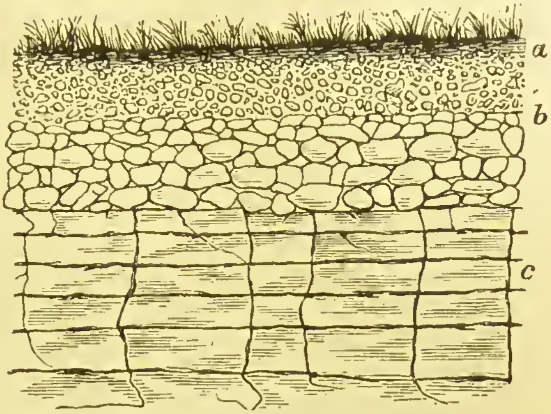


FIG. 44.—Rock passing upwards into Soil.

To render clear and distinct our ideas of what soil is composed of, we will take up a handful of good soil from a field or garden, and examine it. On putting the soil into a large vessel of water, and stirring it up, we may observe the following : (1) little stones of all shapes fall to the bottom—these may be removed; (2) on again stirring, grains of sand will be seen to settle to the bottom—these may also be taken out; (3) on adding a little acid, such as vinegar or hydrochloric acid, to a portion of the soil an effervescence will probably be noticed—this shows that calcareous matter (calcium carbonate) is present ; (4) on leaving the muddy water left after removing the small stones and grains of sand to stand for a day, the finer sediment falls to the bottom, and when we take it up we can see that it is mostly clay, because it is plastic ; after drying some of the mud, we may take a quantity and heat it strongly in an iron spoon. As it gets very hot it takes fire, and a part burns, leaving the rest bleached or reddened. This combustible portion is the *humus*, or decaying organic matter, and it is to the decaying remains of vegetation that the soil chiefly owes its dark colour.

151. **Position and Arrangement of Rocks on the Earth's Surface.**—We have now learnt of what materials the different rocks forming the crust of the earth are composed, and how these rocks have been formed ; the next thing is to learn something about the changes of position that many of them have undergone. The layers of stratified rocks in most cases were formed by the deposition of sediment at the bottom of the sea or of a lake, the fossils they contain showing whether they were marine or lacustrine deposits ; and these beds were originally spread out in a horizontal position, or nearly so. That this must have been the original position follows from their aqueous origin, and we see similar horizontal deposits forming in water at the present time. Water can only deposit material on a level surface or a gentle slope. But we now find these rocks raised into the air, sometimes even forming the summits of mountains. The strata are also no longer horizontal in many cases, but inclined at all angles, sometimes bent and folded in nearly all directions, and frequently broken across by immense

fractures. How has this elevation and displacement been brought about? We cannot suppose that the level of the sea has sunk to the extent required; for strata of marine formation occur, on the Alps and other mountains, at a height of ten or twelve thousand feet. Hence the stratified land must have been lifted up. The sea cannot be elevated or depressed in one place without a general change of level taking place all over the globe, but we know as a fact that such rising as well as sinking of the land is now actually taking place. Sometimes there is a sudden upheaval, affecting a comparatively small district, but of equal if not greater importance are the slow uprisings and sinkings that occur over large areas. It is not necessary to suppose a force acting vertically upwards as the cause of these latter phenomena. Some are probably due to the contraction of the earth's crust, consequent on the slow cooling of the interior, while others are due to the action of subterranean forces and the upheaval of igneous rocks. Whatever be the cause, the consequences are that not only have the strata been lifted up into the air from the bottom of water, but the rocks have been tilted, folded, and broken in the way already referred to.

152. **Inclined Strata.**—When strata have been pushed up at one place more than another they will be thrown into an inclined position. This downward inclination from the horizontal is called the dip of the strata, while the appearance of the edge of the inclined bed at the surface is called the outcrop. These inclined strata may often be seen in quarries, railway-cuttings, &c.

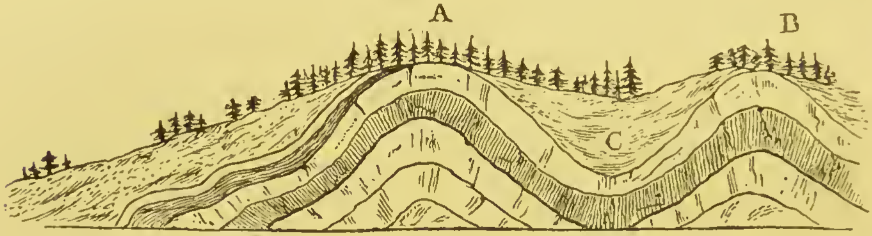


Fig. 45.—Anticlinal and Synclinal Curves.

In some cases the strata have been thrown into a vertical position. Vertical strata of limestone can be seen at many places on the edge of the Pennine chain.

Bent strata often show the following arrangement when seen in section. There is a series of convex and concave bendings, the strata rising and sinking so as to form ridges and valleys. Where the beds have an arched form, and dip away in opposite directions, they are said to be anticlinal; when they form a basin or trough they are said to be synclinal.

Fig. 45 gives a view of such strata as shown in a gorge or cluse of the Jura Mountains in Switzerland. A and B are the anticlinal curves, and C the synclinal.

When beds or strata lie parallel on each other they are said to be *conformable*, but when one set of beds rests on the upturned and worn edges of another we have what is called *unconformable* stratification. The upper strata lie unconformably on the lower. Such arrangement of beds shows a great lapse of time, for the lower beds must have been formed, consolidated, raised into their inclined position, and probably exposed to some amount of wearing, before the upper beds could have been deposited on them.

In cases where the rocks have been too rigid to bend during the action of some mighty force a fracture has taken place, so that very often on one side of the crack produced the corresponding rocks are much higher than on the other. These fractures and displacements of the rocks are called *faults.* Faults vary in size from a few inches to hundreds of feet.

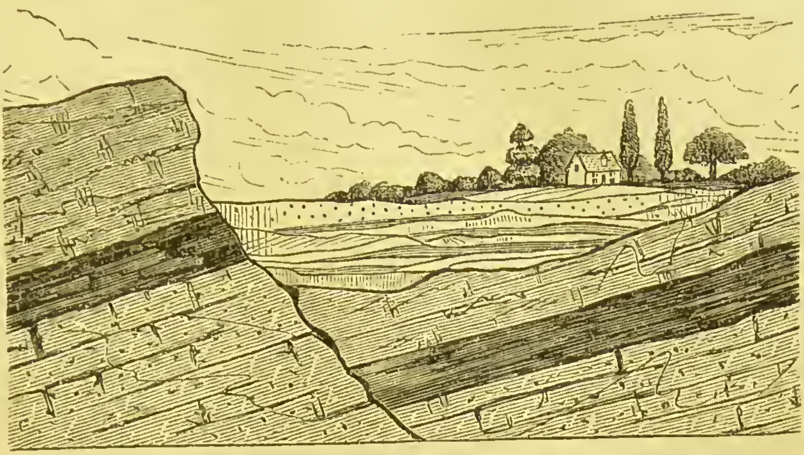


Fig. 46.—Fault, showing Broken and Shifted Beds of Rock.

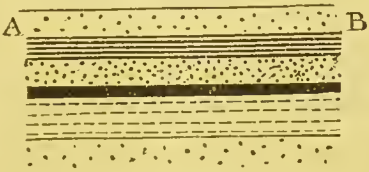


Fig. 47.

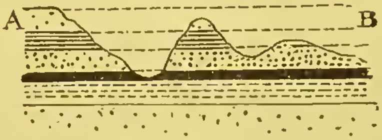


Fig. 48.

Even where the strata have not been disturbed, but lie horizontally as deposited, they have often been carved out in hills and valleys by the action of rivers, rain, and other atmospheric agencies. If we let fig. 47 represent such a series of horizontal strata, and if we suppose that they have been unacted upon by these agents, then A B would represent the surface. This would be of a uniform character, and we should walk over a level surface of soil of all the same kind. But if this district were acted on by rain and rivers, the unequal hardness of the different rocks and the position of the disintegrating agents would soon beget irregularities, so that an exposed section might present such an appearance as that shown in fig. 48; while 'a geological map would now indicate the exposure not merely of the uppermost stratum, but also the outcrop of several underlying beds, somewhat in the manner shown in fig. 49, with probably a river R R running along the bottom of the valley.' (Rutley.)

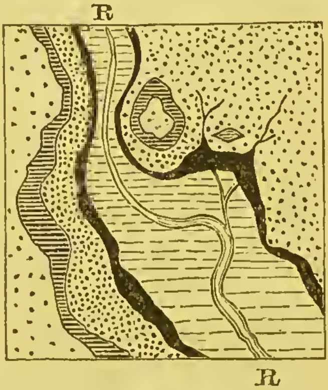


Fig 49.

153. **Denudation** (Lat. *de*, down; *nudus*, bare) is the name

given to the process by which water and other agents break up and reduce the land to a lower level. This denudation or wearing away of rocks is generally described under two heads :

(1) Marine denudation, the action of the tides and waves of the sea on the coast of the land.

(2) Atmospheric or sub-aërial denudation, the action of rain, running water, frost, ice, and air on the rocks of the earth's crust.

These various denuding agents, and the mode in which they work, have been already referred to in speaking of soil, and will be further described in the chapters on the Sea and the Sculpture of the Land.

CHAPTER VII.

INTERIOR OF THE EARTH—VOLCANOES; EARTHQUAKES, AND OTHER MOVEMENTS OF THE EARTH'S CRUST.

154. **Density of the Earth.**—Astronomers have been able to calculate the weight of the earth, and have shown that it is about 5½ times heavier than a globe of the same size composed of water. The mean density or specific gravity of the materials that form the crust is a little less than three. The average density of the earth is thus about twice the density of the rocks forming its crust. We are, therefore, forced to conclude that the interior portions of the earth are specifically heavier—*i.e.* of greater density—than the outside crust. The explanation of this increase of weight in the materials of the earth's interior is a question still in dispute. In consequence of the enormous pressure exerted on the rocks in the interior by the rocks overlying them, some assert that these deeper rocks, composed of the same kind of materials as those in the crust, will be compressed or squeezed into so much less space, that this increase of density is easily accounted for, and that the increase of density would be still greater were it not for the expansive force of the heat in the earth's interior. Others doubt this great compressibility of solid substances, and believe that the interior portions of the globe are composed of heavier and different materials than

those near the surface. These materials are thought to consist largely of metallic elements, such as iron, nickel, and cobalt, either free or forming alloys with one another. It has been pointed out that in this respect the earth's interior would be similar in composition to those pieces of matter flying through space which sometimes fall on the earth as meteorites.

155. **Internal Temperature of the Earth.**—A thermometer on the surface of the earth, or buried only a few inches below the surface, shows variations of temperature depending on the time of the day and the season of the year. But these variations do not penetrate far into the crust. At a distance below the surface of about fifty feet in Britain there is a stratum of invariable temperature, this constant temperature being usually nearly the same as the average temperature of the surface. The depth at which this constant temperature is found varies somewhat with the climate. Below this depth the temperature increases, so that at the bottom of a deep mine the miners usually take off their clothes. The rate of increase varies for different places, being on the average 1° F. for every 60 feet of descent, or 88° F. for every mile. These facts have been ascertained by taking the temperature in mines, borings, and deep wells. In the Rose Bridge Colliery, near Wigan, a shaft has been sunk to the depth of 2,445 feet, and the temperature at the bottom is about 94° F., the average temperature at the surface being 49° F. This gives an increase of about 1° F. for every 54 feet. Water rises from an artesian well near Paris from a depth of 1,800 feet, and this water has a temperature of 82° F., being about 29° more than the average temperature. Other proofs of the high temperature of the interior of the earth are found in the existence of volcanoes sending out molten masses of rock, and in geysers and other hot springs discharging large volumes of heated water. These hot springs occur most frequently in the neighbourhood of volcanoes, but they are also found in other districts. There is one at Bath, the waters of which have a temperature of 120° F.

156. **Interior not Fluid.**—But though there is thus a high temperature existing in the earth's crust, and though there is a more or less regular increase of temperature with depth, it does not follow that the interior of the earth is in a liquid state. If the rate of increase (1° F. for every 60 feet) continues to depths far below those observed, it is certainly true at a depth of about two miles the rocks would be as hot as boiling water, while at a depth of forty or fifty miles the heat would be sufficiently great to melt any rock if *at the surface.* But at such a depth the pressure would be very great, and under increased pressure the melting-point of solid bodies is raised. They require more room when melted than when solid, and if the pressure prevents them from getting that space they cannot melt. We thus see that even if the temperature at great depths be above the fusing-point of the rocks they may be kept in the solid state by intense pressure. But we are not certain that the temperature at great depths does follow the regular law of increase observed in the rocks of the crust. In some places the increase of temperature is much greater than the average given above and in some places much less. It varies from 1° F. for every 20 feet of depth to 1° F. for every 100 feet. It has been noticed that the rate of increase is very high in places that have been recently the seat of volcanic

activity. It may be pointed out that the calculations of astronomers show that the observed motions of the earth are inconsistent with a fluid interior. The most probable conclusion, therefore, is that the earth is mainly solid throughout, but that liquid spaces or cavities are formed by diminution of pressure or the inflow of water, both of which might reduce the fusing-point of the rocks, and from these spaces volcanoes derive the material which they eject.

VOLCANOES.

157. **Definition of a Volcano.**—It is not easy to give a satisfactory definition of a volcano, but we can easily avoid some of the mistakes often committed, and on which we shall afterwards remark. Here are examples of more or less accurate and complete definitions which will serve our purpose, and which will be better understood shortly. 'A volcano is a more or less conical hill or mountain, usually truncated, communicating with the interior of the earth by a pipe or funnel, through which issue hot vapours and gases, and frequently loose fragmentary materials, and streams of molten rock.'—*Prof. J. Geikie.* 'A volcano is a more or less flat cone which is, or has been, connected by a channel with the depths of the earth, and which serves, or has before served, as an outlet for gaseous, solid, and glowing liquid masses.'—*Credner.*

It will be noticed that in this last definition there is implied the fact that some volcanoes cease to send forth materials and become inactive. Hence the distinction between *active* and *extinct* volcanoes. 'An active volcano may be defined as a passage or pipe which affords to deep-seated mineral matter in a state of fusion the means of transmission through the earth's crust, and of egress at its surface. A passive or extinct volcano is one in which this communication is obstructed, either by a plug of solidified lava, or by accumulations of fragmentary matter—a dissipation, temporary or permanent, of the eruptive energy permitting the solidification of the molten matter. Should an augmentation of the eruptive force occur, the plug will either be shattered and ejected in the form of lapilli and ashes, or re-melted and poured out as lava ; but if it be unable to reopen the old passage new vents may be produced, either within or without the lip of the crater.' (Rutley.) It will be noticed that in the definition of an active volcano, last given, no mention is made of a hill or mountain. No doubt this is because the essential and most important part of the volcano is the pipe or tube through which the ejected materials are sent, and also because the hills or mountains when present are built up out of the materials sent out, and are thus the results, and not the causes, of the volcanic activity. In the definition of an extinct volcano we must also notice that though no volcanic action of any kind is now taking place, yet it is possible that activity may again burst forth. Before A.D. 79 Vesuvius might have been regarded as an extinct volcano, for the great crater called Somma, which then occupied the summit, had never been known to be in activity. But in that year it came into sudden activity; half of the crater was blown away, a great eruption took place, and the new crater, the present Vesuvius, was formed within the old one. It has continued in activity at intervals ever since, new cones being frequently formed, or old ones altered in shape. In the Auvergne district of central France many denuded cones of extinct volcanoes still exist. No record or tradition of any eruption, however, remains. Even when the cone has entirely disappeared, the neck or solidified plug of lava may still remain to fix the site of a volcanic vent. When a volcano only throws out steam and gases, it is said to be *dormant*, or in a quiescent state. Renewed activity may occur at any time. A dormant volcano usually forms only a small cloud of steam near its summit.

158. **Signs of an Eruption.**—In some cases eruptions take place without any warning symptoms, but in other cases there are indications for various periods beforehand. Loud rumbling sounds are heard from the mountain, and as these increase in intensity shocks of earthquake follow the noises, and the quakings return at shorter and shorter intervals. These form one of the surest and most general signs of an eruption, especially when the volcano was previously quiet. The water in wells and springs sometimes ceases to flow. This is no doubt owing to the disappearing of the water into rents and fissures below. At other times springs issue forth in fresh places, or wells which were before pure become muddy. The sea, too, may be affected by the ground shocks, rising and sinking in an unnatural way. But all these signs may fail and the eruption come quite suddenly, as did that of Vesuvius in 1853.

159. **Phenomena accompanying an Eruption.**—After the signs and warnings, or without them, as may be, the vapour from the crater at the top of the vent increases in volume while the lava ascends in the pipe or funnel, and the phenomena usually occur in the following order:—

(1) The outbreak begins with a mighty shake of the mountain, and the highly expanded steam and gases burst forth, scattering in tremendous explosions minute fragments of the lava. These explosions are quickly repeated, and huge ball-like masses of steam are driven upwards towards the sky. If there is little wind these rise nearly straight up and then spread out to form a horizontal cloud, so that the appearance of the column and cloud is like that of an Italian pine-tree called the stone-pine. This pine-tree column, consisting of steam, gases, and fine particles of volcanic dust, reflects the glowing redness of the masses of heated rock and molten lava in the crater below, producing the appearance of flames. That they are not real flames, but produced by the reflection of the lava glow in the crater

on the millions of steam bubbles in the column, is evident from the fact that they show no fluttering motion, and are not driven out of their steadiness by any wind. The steam-cloud soon begins to condense, and a great downfall of rain occurs, sweeping the loose volcanic dust down the slopes of the mountain, and forming torrents of mud-lava that often do more destruction than the real lava stream. Lightning and thunder accompany such an eruption, the electricity being probably generated by intense friction of the steam and dust particles.

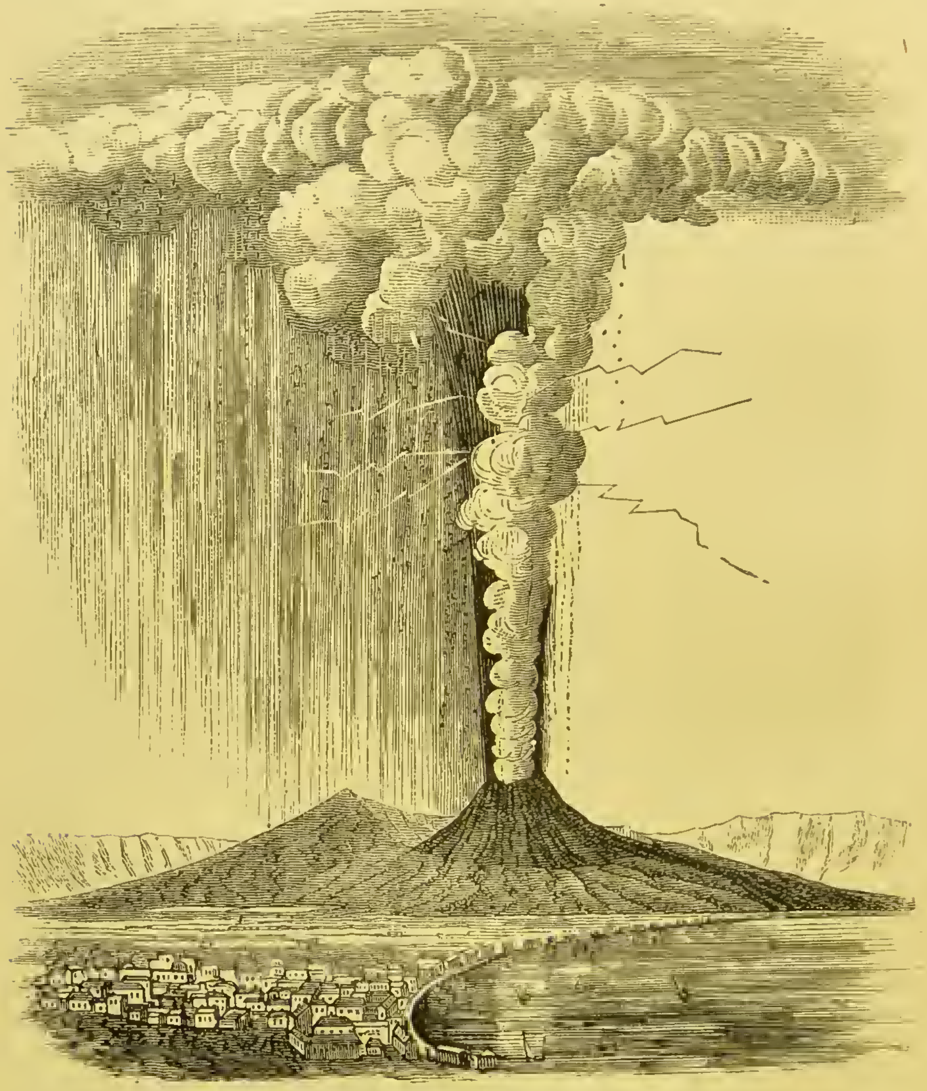


FIG. 50.—Vesuvius in Eruption, October 1822, showing Pine-tree Column of Steam, Falling Rain, Ashes, and Flashes of Lightning.

(2) Closely following and partly accompanying the outburst of steam and gases there is a great discharge of dust, ashes, and stones. These are derived partly from the lava in the funnel, and partly from the walls of the

crater, and either fall back on the sides of the cone, increasing the size of the mountain, or into the crater, whence they are again ejected, each time being reduced to finer powder. Some of the very fine powder is carried to a great height in the steam column, and may be driven immense distances by the wind.

(3) The lava itself rises up the central funnel, and either overflows the lip of the crater or bursts its way through fissures in the sides of the cone. In this case there form on the hill secondary centres of eruption, throwing out cinders and ashes, and building up small *parasitical cones* on the sides. From the streaming lava itself great clouds of steam arise. The outflow of lava usually marks the crisis or culminating-point of the eruption.

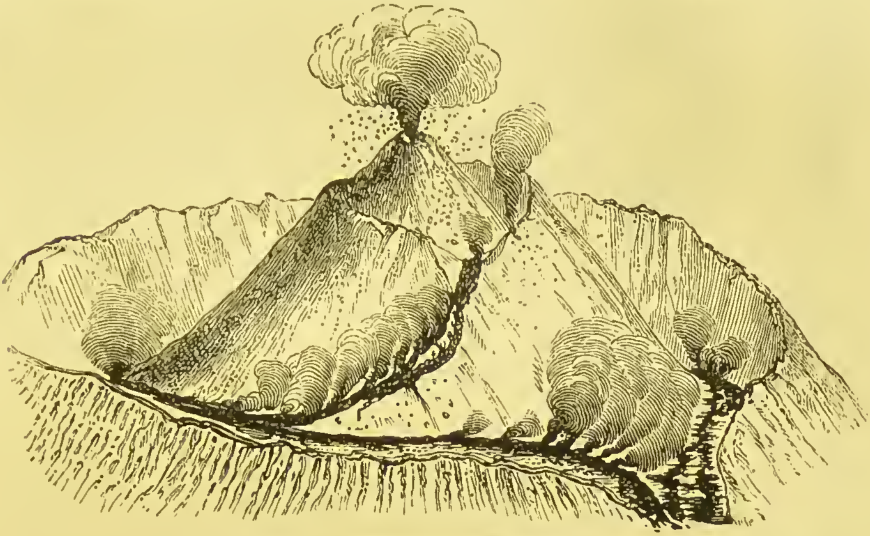


FIG. 51.—Summit of Vesuvius in 1756.

This sequence of events is not always followed, and there have been many eruptions where only steam and ashes have been sent forth. At other times there has been a great outburst of lava with little steam and ashes.

160. **Products of an Eruption.**—We may place the products of eruption under the following heads: (1) steam and gases; (2) fragmental materials; (3) lava.

(1) *Steam and Gases.*—The most abundant of the substances ejected is steam or water gas. As before stated, it is erupted in large globular masses, each of which is the product of an explosion in the molten lava of the funnel or crater.

But besides steam there are the following gases: carbonic acid, hydrochloric acid, sulphur dioxide, sulphuretted hydrogen, sulphuric acid, nitrogen, and ammonia. Some of these volatile substances react on one another and on the heated rocks, forming a number of secondary products. Thus the sulphuretted hydrogen and the sulphur dioxide produce by their reaction water and free sulphur ($SO_2 + 2SH_2 = 3S + 2H_2O$). This free sulphur thus produced, not sent out of the volcano as such, is deposited in the fissures and cavities of the crater.

The hydrochloric acid acts on the rocks, uniting with the iron to form yellow ferric chloride. The acid gases form with the heated lavas other soluble salts, as sulphates, chlorides, carbonates, &c. The free hydrogen is inflammable, and burns with a pale blue flame, which is sometimes coloured by metallic oxides; but, as already remarked, the huge red glow so conspicuous at night is not due to flame, but is only the reflection on the steam-cloud of the heated lava below.

(2) *Fragmental Products.*—These consist of the solid materials sent out during an eruption, and are of various sizes and kinds. Some of the broken material is formed of pieces torn off the rocks through which the eruption has occurred, but most of it consists of ragged cindery lumps blown away from the lava bubbling and seething below. The larger angular pieces are spoken of as *volcanic blocks.* At times masses of fluid lava are sent spinning into the air, and these during their rotation acquire a globular, oval, or pear-shaped form, and hardening as they fall are called volcanic bombs. A *volcanic bomb* is thus a round, oval, or pear-shaped mass of cooled lava that has acquired its form when rotating in the air. It may vary in size from a few inches to two or three feet in diameter. It is often cellular inside, the lava having been distended with bubbles; sometimes hollow, but occasionally it has a solid nucleus.

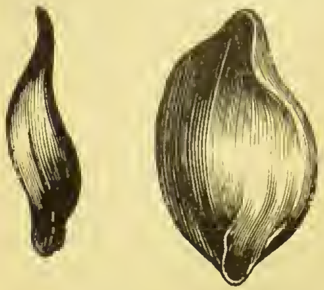


FIG. 52.—Volcanic Bombs.

Scoriæ or *cinders* is the name given to the rough, angular, cindery-looking material sent out from the volcano, or forming the slag and scum on the surface of some lava streams. The word 'cinders' only refers to the appearance of the substance, and does not mean that it is a partly burnt fuel like the cinders of a fire. Scoria resembles more the slags and clinkers of an iron furnace, which are the partly fused glassy rock.

Pumice is the light, porous, rocky material sent out from the crater or formed on the surface of glassy lavas. Its composition and description will be found in a previous paragraph (139).

Lapilli are small ejected volcanic fragments varying in size from a pea to a nut.

Volcanic ash or *dust* is the fine light grey powder or dust formed partly from the bubbling lava, and partly by the attrition or friction of the ejected loose materials. These often fall back again and again into the crater, and are thus reduced to smaller and smaller particles, some as large as sand grains, but others finer than the finest flour. It is so called from its resemblance to the ashes of our fires, not because it is the incombustible mineral residue of a fuel. So minute are the particles of this volcanic dust, that it readily finds its way through the smallest chinks into houses, boxes, drawers, &c. This finely divided volcanic dust is sometimes carried by the steam column to a height of several miles, and then borne away by the upper currents of the atmosphere to verv great distances. Dust from the

Icelandic volcanoes, for instance, has often been known to fall in Norway and Sweden. The eruption from Vesuvius in 472 A.D. carried ashes over as far as Constantinople. It has even been met with by ships at sea at a distance of more than 1,000 miles from the volcano that has thrown it out. In this way volcanic dust becomes spread all over the ocean. Some of the pumice sent out from volcanoes is also cast into the sea, and carried away by the waves far from land. In time this pumice sinks. There is thus formed on the floor of the ocean a deposit of these volcanic materials, so that from the deeper portions (above 2,000 fathoms), where no sediments are brought, and where no calcareous remains fall, as they are dissolved before they reach the bottom, pumice and ashes have been dredged up, as well as certain red, grey, and chocolate-coloured clays, due to the decomposition of these volcanic materials. The presence of this deposit of red clay was one of the most important facts discovered in the expedition of the 'Challenger.' The colours are due to the presence of oxide of iron and oxide of manganese. A remarkably violent eruption took place on the small island of Krakatoa, in the Sunda Straits, between Java and Sumatra, during the year 1883. Up to May 1883 the volcano, which formed a peak nearly 3,000 feet high, had been inactive for a long time. In that month shocks began to be felt, and steam was seen issuing from the summit. The activity of the volcano gradually increased, until a series of tremendous explosions on August 26 and 27 blew away the cone and the greater part of the island. The sea in the neighbourhood was thrown into huge waves, which, sweeping over the coasts of Java and Sumatra, destroyed several villages, and drowned 30,000 people. Immense quantities of pumice, lapilli, ashes, and the finest dust were thrown into the atmosphere. Ships within a distance of twenty miles were in total darkness during the 27th, and the dust was observed falling by vessels at a distance of 1,000 miles. The sea was covered for several weeks with a great thickness of floating pumice. So great was the concussion produced in the atmosphere that the air vibrations disturbed the whole atmosphere of the globe. The finest particles of dust remained for a long time floating in the upper currents of the air, and were carried by the wind all over the earth. The presence of this impalpable volcanic dust caused a peculiar glow in the sky at sunrise and sunset for several months in nearly every country, and rain and snow which fell in Spain and other distant parts were found to contain the same materials as those forming the ashes from Krakatoa.

161. **Lava Streams.**—The composition and varieties of lava have already been described in speaking of igneous rocks. The rate at which a lava stream flows varies considerably. Sometimes it flows down the mountain cone like a rapid river, but usually it is very viscous and flows slowly. The slowly moving lavas have a wrinkled and twisted surface like coils of rope, but the currents that move quickly usually give off great quantities of steam, and this causes the upper layer to become scoriaceous or cindery. It thus appears that a large mass of water imprisoned in the lava increases its mobility. This upper layer of scoriæ is very vesicular, and the ragged, rough masses are very difficult to walk upon. A section of a lava stream has been shown and described in Fig. 40. All rocks are bad conductors of heat, and therefore when once a solid crust has formed, the interior portion retains its heat for a long time—in very thick lava streams for many years. During the slow cooling it often splits up into more or less regular columns, such as those seen in the mud of a dried-up pool. This explains the columnar structure of basalt already referred to (par. 139).

It should be remembered that the fine ashes, lapilli, pumice, bombs, and scoriæ are all formed from the lava, and have therefore the same composition as the lava from which they are derived.

As already mentioned, lavas are mainly silicates of the following metals—aluminium, magnesium, calcium, iron, potassium, sodium—in varying proportions; these silicates being formed by the union of the binary compound silica (SiO_2) with the oxides of these metals. The acid lavas, or those containing a large proportion of silica (66 to 80 per cent.), as trachyte, are lighter in colour and more difficult to melt than the basic lavas, as basalt, which only contain 45 to 55 per cent. of silica. In all cases oxygen forms nearly one-half the weight of all lavas (see par. 139).

Some lava currents are congealed before they reach the bottom of the cone, while others reach many miles. Lava streams from Vesuvius have several times reached the sea, a distance of about five miles. A stream came from one of the numerous lateral cones of Etna of 1669 which reached a length of fifteen miles, with a width in some places of five miles. It ran the first thirteen miles in twenty days. In 1783 a stream fifty miles long and twelve miles broad issued from Skaptar Yokul in Iceland. Where a volcano reaches above the snow-line, like Cotopaxi, the outpour of lava sometimes produces great floods. Eruptions occasionally take place beneath the surface of the sea, throwing up huge columns of water, and in some cases causing an island to appear. In 1831 an island called Graham's Isle was thrown up off the coast of Sicily to a height of 600 feet by a submarine eruption. In the course of a few months, however, this scoria cone was washed away by the waves, and the materials spread over the sea bottom.

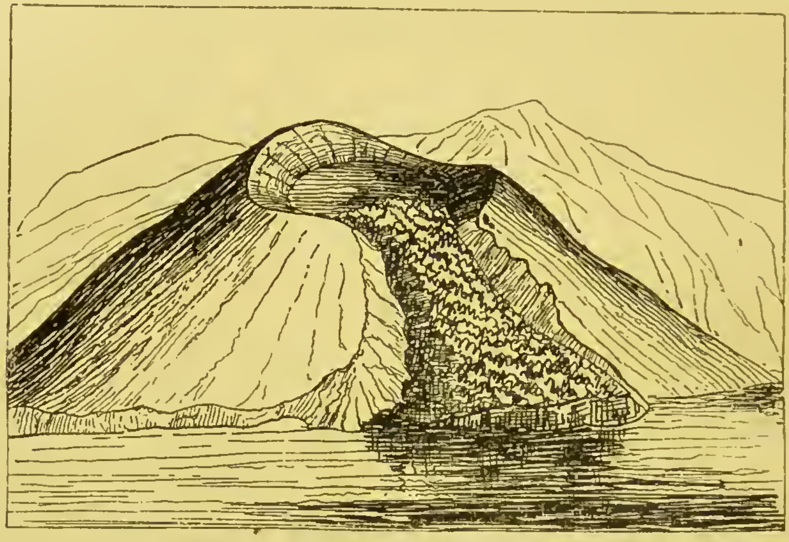


FIG. 53.—Breached Pumice Cone with Obsidian Lava Stream.

162. **Cause of Eruptions.**—It is plain, from the enormous discharge of steam during volcanic eruptions, that the vapour of water plays a very important part in these phenomena. The expansion of large volumes of steam when under great pressure is believed by many writers to be the chief cause of the rise of lava, as well as the cause of the ejection of the cinders and ashes. When the water penetrates into the cavities where molten matter is present,

the steam generated is thought to exert such force as to press up the lava in the duct of the volcano, and then burst in huge bubbles as the pressure on it lessens near the surface. Other writers state that the rise of lava is due to a slight shrinking and contraction of the earth's crust.

163. **Structure of Volcanic Mountains.**—The cones and craters of volcanoes have many varieties of form, and during an eruption great changes are often produced. They range in height from a few feet to nearly four miles. Vesuvius is not quite 4,000 feet, Etna is 11,000 feet, and Cotopaxi, in Peru, 18,876 feet. The cone which constitutes the mountain is built up of the materials ejected from the crater, though some of the finer materials are carried, as previously shown, by the winds and distributed over the sea and distant lands. The materials, however, mostly descend round the spot where they are thrown out, and the thickness of the deposit becomes less and less at a greater distance from the vent. There is thus built up a conical structure, truncated or cut off at the top, the materials of the sides of the cone being arranged in layers sloping outwards, but the materials that fall within the crater slope inwards. In some cases, owing to the action of the wind, the cone is much higher on one side than on the other.

Some cones are built up almost entirely of scoriæ or cinders, and these constitute the fragmentary materials sent out. There is a large number of such *cinder-cones* among the extinct volcanic peaks in the Auvergne district. In the Lipari Islands are found cones almost entirely composed of pumice. Such *pumice-cones* have been formed of the material exploded from the surface of a glassy lava.

Some cones are mostly formed of the smaller fragmentary materials called lapilli and ash. As already explained, rain often causes this to come down as mud, which consolidates in layers of volcanic tuff or tufa. The *tuff-cones* have not such a steep slope as the cinder-cones.

There are cones composed partly of scoria and partly of tuff, the materials being arranged in layers so as to have a stratified arrangement.

Cones are found which are almost entirely composed of lava flows. The lava, as it wells out, either accumulates in dome-shaped masses or spreads out on all sides in such a way that a great conical heap is formed with a very wide base. The great volcano of Mauna Loa in the island of Hawaii, one of the Sandwich Islands, is a lava cone, and has a height of nearly 14,000 feet, and a breadth at the base of seventy miles. The slope is therefore very small compared with the slope of such volcanoes as Etna and Vesuvius. Its crater is a huge pit two to three miles across and over 700 feet deep, at the bottom of which is liquid lava. Kilauea is another great crater on the side of the same mountain, but sixteen miles distant from Mauna Loa. The crater is several hundred feet deep and nearly three miles across. In the centre of this huge pit is a seething, fiery, liquid lake of lava. The molten rock heaves and bubbles with the fluidity of molten iron, dashing in waves against the solidified walls of lava, or throwing up on its surface cones and fountains of lava. At intervals of a few years the fiery liquid rises up to the brim of the crater and overflows, or, as is more usual, bursts through rents in the side of the mountain. The two craters do not appear to have any connection, though situated on the same mountain, and they are different from most other volcanoes in only discharging lava, which is of a very glassy kind, and in their discharges being seldom accompanied by any great explosions.

But most of the volcanic mountains of the globe are built up partly of fragmentary materials and partly of lava that has run down the sides.

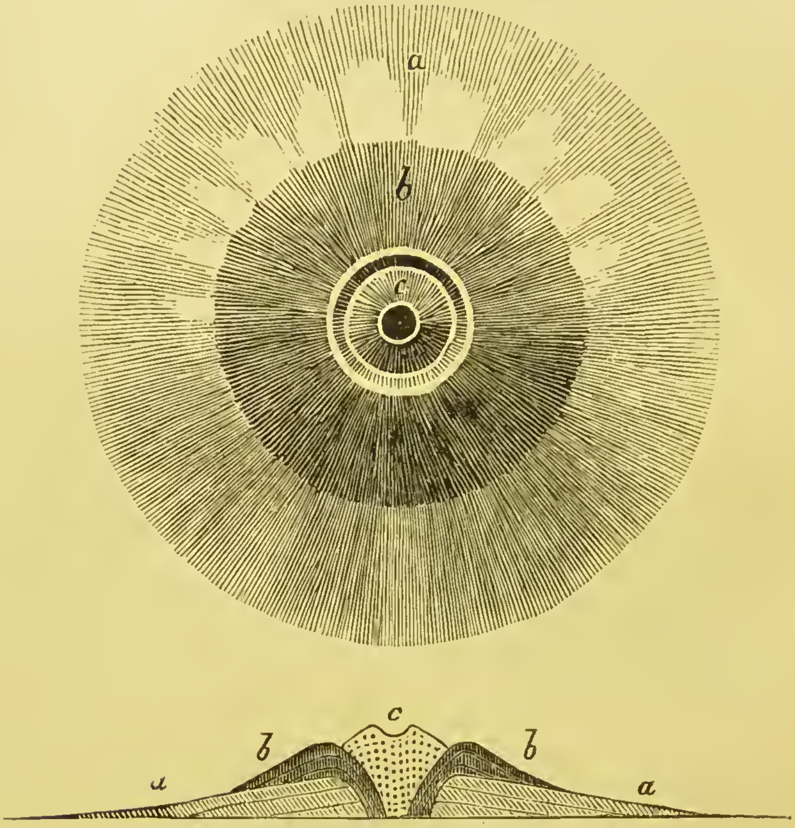


FIG. 54.—Plan and Section of a Composite Volcanic Cone.
a, tuff; *b*, lava; *c*, ashes and scoriæ.

These alternate in such a way as to give the cone a stratified appearance when seen in section.

Such cones are called *composite cones*. Here are two views of such a cone, the first exhibiting the cone as seen from above, and the second showing it in vertical section.

But even this view of a composite cone is not quite complete. As the molten lava is being forced up from below, some of it is injected into cracks and fissures in the cone, and at times one of these fissures opens on the flanks of the cone, and a small lateral cone is then produced. But much of the lava injected into these fissures solidifies there, and forms veins or walls of rock known as dykes. These dykes traverse the layers of ash, tuff, and lava previously sent out. Fig. 55 is an ideal section of such a dyke-traversed composite cone, showing also lateral parasitic cones. We may therefore say that three kinds of materials enter into the structure of most volcanic cones :—(1) loose scoriæ, lapilli, and ash, arranged in layers on the side and giving it a stratified appearance ; (2) lava streams that have been sent out from the crater or from fissures in the sides, and, flowing down the cone, have become interstratified with the loose materials ; (3) dykes or masses of lava filling up cracks and fissures in the cone.

164. **The Crater** of a volcano is the cup-shaped depression or chasm found at the summit or on the flanks of the hill, and at the bottom of which is situated the duct or pipe that communicates with the heated interior. It has usually a circular form, owing to the expansion in all directions of the explosive vapours that rise from below. Craters vary in size, some of the very large ones being more than a mile in diameter and more than a thousand feet deep. The inner walls of the crater frequently present a rough and rugged appearance. The bottom of the crater when quiescent is a rough plain, with here and there heaps of loose material giving off steam and hot vapours. At night the glowing lava may be seen through fissures.

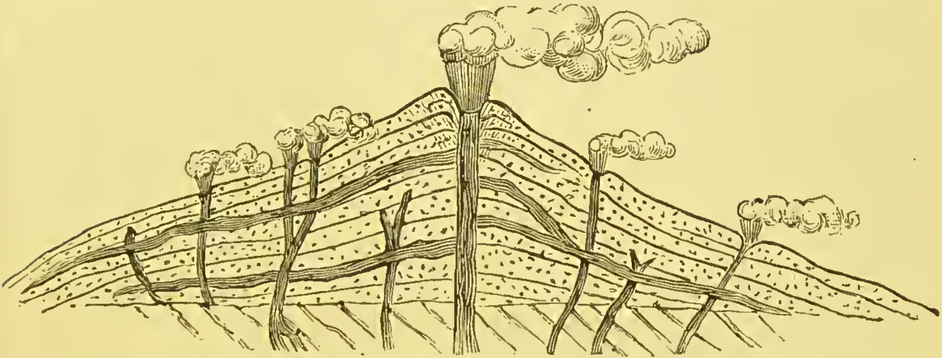


FIG. 55.—Ideal Section of Volcano showing Dykes of Lava and Lateral Craters forming Lateral Cones.

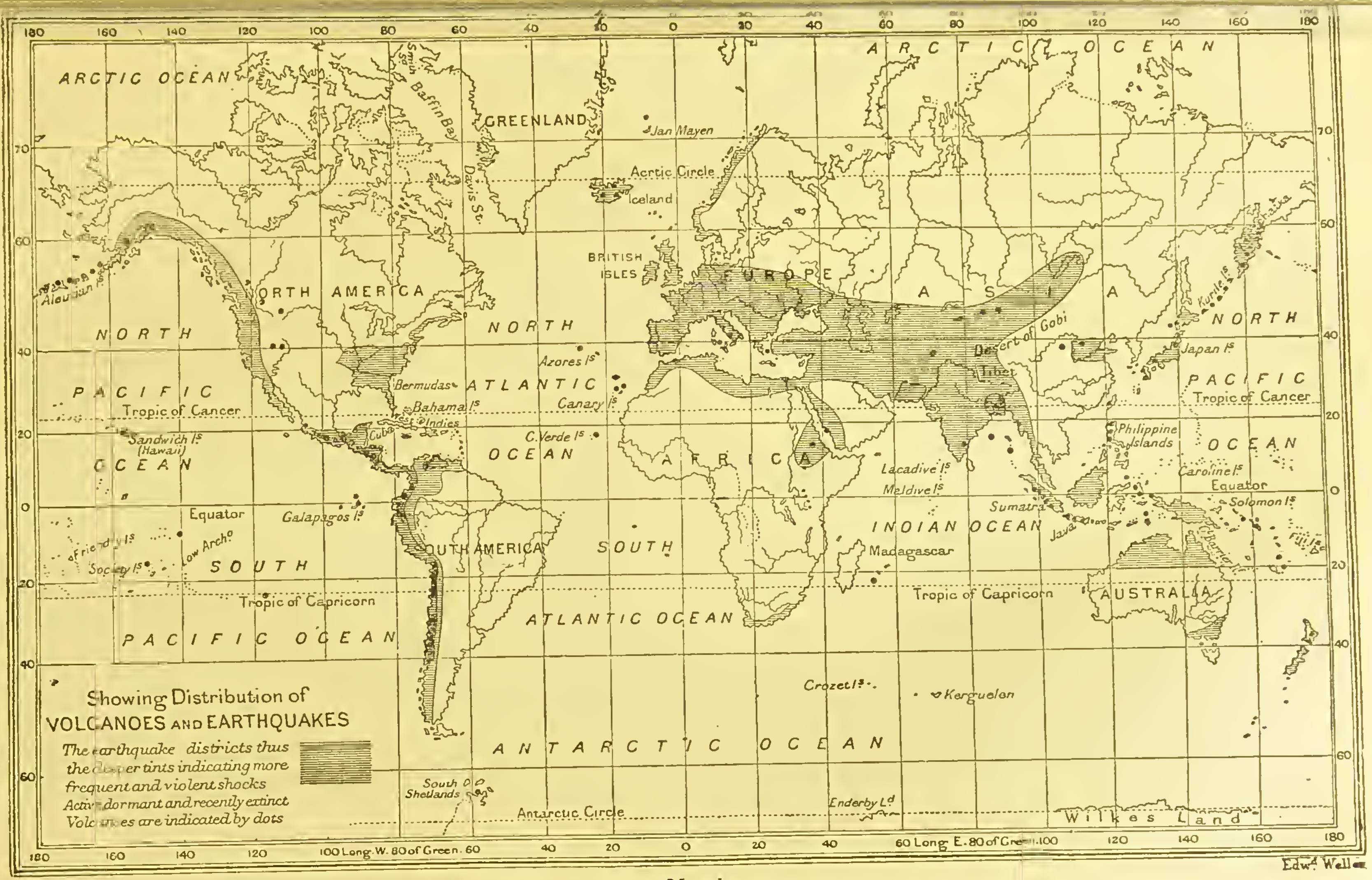
165. **Errors about Volcanoes.**—We often find, especially in older books, many mistakes in the definition of a volcano. For example, a volcano is often described as 'a burning mountain sending out fire and smoke from its summit.' Now, as we have seen, the essential part is the duct or pipe communicating with the heated interior, and at the beginning there is often no mountain at all, the mountain being built up of the materials ejected. The fiery glow that is usually seen is not due to burning or combustion, for this and the supposed flames are caused by the reflection in the steam-cloud of the red-hot lava in the crater below. What is spoken of as 'smoke' is only the condensing water vapour sent out in great globular masses from the heated lava. Real steam is invisible, but as soon as it comes into contact with the colder air it begins to condense into minute particles of 'water-dust.' These minute particles of water-dust form what is usually spoken of as the steam column, which after attaining a great height is still further condensed, and falls in drops as rain. Nor does the volcanic action always take place at the summit of the hill where one has been formed, as eruptions frequently occur through fissures formed in the sides.

For more correct definitions than the above see paragraph 157.

166. **Number, Position, and Distribution of Volcanoes.**—The number of active volcanoes now found on the surface of the earth is a little over 300. If we include those extinct volcanoes which still possess a conical form and signs of a crater we shall probably find the total nearly 1,000. One of the first things to notice regarding the *position* of volcanoes is the fact that they are mostly situated near the sea, on islands, or on the borders of continents. The only exceptions to this rule are five or six volcanoes said to exist in Central Asia, in the Thian Shan Mountains and Manchooria, and two or three in Central Africa.

Another interesting fact regarding their position is that they are found in all regions of the globe, from Iceland and the Aleutian Islands, through the tropics to the Antarctic continent, though they are more numerous in the torrid than in any other zone. They seem to follow certain lines, as will be seen on reference to the map. Over 200 of the active volcanoes, too, are found on the coast-lands or islands of the Indian and of the Pacific Oceans. On the east side of the Pacific we can trace a line of volcanoes through the lofty chain of the Andes, then through Central America and along the west coast of North America. The volcano of Jorullo, on the coast of the Mexican table-land, is noteworthy from the fact that it was entirely built up to a height of over 1,300 feet in a single eruption in 1759. This line then crosses over from North America by the Aleutian Isles to Kamtschatka on the western side. In Kamtschatka there are 12 active volcanoes, in the Kurile Islands 10, and in the Japanese islands over 20. From Japan the line of volcanoes passes through Formosa and the Philippine Islands to the Malay Archipelago. In this great group of islands volcanic activity seems at its height. In Java there are about 40 volcanoes, and in Luzon and the Philippines 21. In the Malay Archipelago the volcanic line bifurcates. One branch goes westward through Java and Sumatra, along the eastern side of the Bay of Bengal; another branch turns to the south-east through Celebes, New Guinea, the Solomon Islands, and the New Hebrides. A continuation of this line passes into New Zealand, and to Mount Erebus and Mount Terror in the Antarctic continent. Another great volcanic line may be traced down the eastern side of the Atlantic, from Jan Mayen and Iceland through the extinct volcanoes of the Faroe Islands and those of the west of Scotland to the Azores, Canaries, Cape Verde, and other volcanic islands lying off the coast of Africa. This line appears to be connected with a great submarine ridge that runs down the middle of the Atlantic. One branch from this passes into the West Indies, where there are six active volcanoes, while another branch passes into the Mediterranean. Vesuvius is the only active volcano on the mainland of Europe, but on the islands of the Mediterranean there are four or five—viz. Stromboli and Vulcano in the Lipari Islands, Etna in Sicily, Santorin and Nisyros in the Grecian Archipelago. It is believed that this linear arrangement of volcanoes is owing to the fact that they occur on lines of fissures in the earth's crust. The great volcanic bands just described run very near to the lines of great mountain chains, and probably owe their positions to the great lines of fissures on the globe. Even in a smaller group, as on the island of Vulcano, the craters often show this linear arrangement, although there are some cases where the vents do not follow the line of fracture in the earth's crust.

167. **Solfataras, Mud Volcanoes, &c.**—After the energy of a volcano has declined, it sometimes passes into what is called the *Solfatara stage.* A


Showing Distribution of
VOLCANOES AND EARTHQUAKES
The earthquake districts thus
the deeper tints indicating more
frequent and violent shocks
Active dormant and recently extinct
Volcanoes are indicated by dots
ARCTIC OCEAN
ARCTIC OCEAN
Smith Sd
Baffin Bay
Davis St.
GREENLAND
Jan Mayen
Arctic Circle
Iceland
BRITISH ISLES
NORTH AMERICA
EUROPE
ASIA
AFRICA
SOUTH AMERICA
AUSTRALIA
Aleutian Is
NORTH PACIFIC OCEAN
Tropic of Cancer
Sandwich Is (Hawaii)
Equator
Friendly Is
Society Is
Low Archo
SOUTH PACIFIC OCEAN
Tropic of Capricorn
Galapagos Is
Bermudas
Bahama Is
West Indies
Cuba
NORTH ATLANTIC OCEAN
Azores Is
Canary Is
C. Verde Is
SOUTH ATLANTIC OCEAN
South Shetlands
Antarctic Circle
ANTARCTIC OCEAN
Crozet Is
Kerguelen
Enderby Ld
Wilkes Land
Desert of Gobi
Tibet
Lacadive Is
Maldive Is
INDIAN OCEAN
Madagascar
Sumatra
Java
Tropic of Capricorn
Kurile Is
Japan Is
NORTH PACIFIC OCEAN
Tropic of Cancer
Philippine Islands
Caroline Is
Equator
Solomon Is
Fiji Is
Gt Barrier
100 Long. W. 80 of Green. 60
60 Long. E. 80 of Green. 100
Edwd Weller

MAP I.

solfatara consists of cracks or fissures from which various kinds of vapours are sent forth. These vapours contain sulphur, chloride of sodium, alkaline sulphates and other substances, and these are often deposited on the lips and sides of the orifices. The smoking cracks in Tuscany are known as *soffioni*, and the issuing vapours contain boracic acid. *Fumaroles* are fissures, often on the surface of a lava-flow, from which steam and other gases are ejected. *Mud volcanoes* or *Salses* are vents from which mud and water are ejected. The mud usually forms in a conical mound around the orifice, but this seldom rises above twenty or thirty feet. There are groups of mud volcanoes in Trinidad and in the neighbourhood of the Caucasus Mountains, the discharges from which contain naphtha or petroleum.

168. **Earthquakes.**—Earthquakes are vibrations, or forward and backward motions of the ground, caused by a wave of elastic compression passing through the crust of the earth. That the movement is of the nature of a wave is evident from the fact that it is not felt at the same time and with the same force over the whole of the district affected. It appears to start from a centre and spread out with diminishing intensity in all directions, and consists of several successive movements ending very gradually. Further, trees, steeples, and other tall objects have been noticed to sway backwards and forwards like the mast or funnel of a ship rocking on the sea. Besides this wave-like motion there is usually a vertical uplifting movement, and rumbling noises are heard both from the ground and in the atmosphere. The study of earthquakes is called Seismology (Gr. *seismos*, an earthquake; and *logos*, a discourse), and the instruments used in the study are known as seismographs and seismometers.

169. **Number and Distribution of Earthquakes.**—Earthquakes are of much more frequent occurrence than is usually supposed. Probably one occurs at least every week in some part of the world, but most of them are only slight shocks. The most violent earthquakes take place in volcanic regions, though some districts that suffer from these movements are free from volcanoes (see map). Still, it is certain that the two phenomena are connected, for the most violent earthquakes occur in the neighbourhood of volcanoes, and earthquake shocks often precede and accompany volcanic activity. It has also been noticed that a series of earthquakes in one district has stopped on the outbreak of a volcano in an adjoining district. The great earthquake region of the Old World is a district stretching from the Azores, along the northern shores and the islands of the Mediterranean, through Asia Minor to the Thian Shan Mountains. In the New World the western shores of South America are frequently visited by intense shocks. Among the Andes of Chili a shock of some kind is said to occur every few days. The Japanese islands are also frequently visited by earthquakes, and special attention is given to these phenomena at the Imperial

College of Tokia. The earthquakes occurring in Britain are always slight. Nearly one-third of those known have taken place in the county of Perth. On April 22, 1884, an earthquake occurred in the neighbourhood of Colchester which damaged some of the buildings.

170. **Causes of Earthquakes.**—It is not easy to assign the causes of earthquake action. Some of the slight tremors have been connected with variations of atmospheric pressure and with the attraction of the sun and moon, but it is plain that the more violent shocks arise from causes in the interior of the earth. Some of them may be consequences of the contraction of the earth's crust on cooling, by which great thicknesses of strata are broken and displaced; others may arise from the sudden generation and expansion of steam; while others may be the result of the falling in of immense cavities in the earth's crust. By observing the position of the place where the shock is vertical, and by ascertaining the angle at which the earth-wave reached the surface at other places, it has been found possible to determine the position of the place in the earth's crust where the shock originated. It is interesting to know that the depth of the point of origin is believed to be in all cases less than thirty miles.

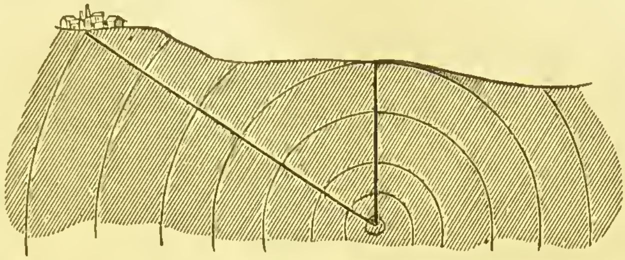


Fig. 56.—Diagram to illustrate Propagation of Earthquake-wave, and the Mode of Calculating the Depth.

171. **Effects of Earthquakes.**—We are very prone to imagine that earthquakes are among the mightiest forces affecting the surface of our earth. This is a mistake, for, although they often produce great destruction of life and great devastation among buildings, their permanent effects are often very slight. Yet at times large masses of rock and earth are displaced, changes of level are produced, and fissures formed in the surface of the ground. The coasts of Chili and New Zealand have several times been raised by earthquakes. At Cutch, on the delta of the Indus, an earthquake in 1819 produced a depression in one part and an elevation in another. The greatest effect is produced when the origin of the shock is beneath the bed of the sea. The earth-wave produced in the solid land causes huge sea-waves to form, and the distance to which these sea-waves extend is often very great. The sea-wave of the Iquique earthquake in 1877 was felt in all parts of the Pacific Ocean, from New Zealand in the south to the shores of Japan in the north. Much of the destruction produced at the great Lisbon earthquake in 1755 was owing to great sea-waves thirty to sixty feet high coming into the Tagus about an hour after the buildings of the town had been overthrown by the shaking of the ground. This earthquake was felt over the greater part of Europe, and even in North Africa. At first the water of the sea is usually seen to withdraw a considerable distance, and then a mighty inrush of large waves follows. The inhabitants of the western coast of South America know so well what this drawing back of the water means, that they take it as a warning, and often save their lives by escaping to the hills. In 1724 Lima was destroyed by an earthquake, and on the evening of the same day a mighty sea-wave eighty feet in height came over Callao. In August 1878 a great part of Peru and Ecuador was

devastated by an earthquake, and a great sea-wave overwhelmed Arica, every vessel in the harbour being either wrecked or carried far inland. The rate at which the great sea-waves caused by earthquakes travel has been used as a means of calculating the average depth of the ocean in which they occur.

172. **Slow Movements of Elevation and Subsidence.**—Besides the sudden changes of level produced by volcanic eruptions and earthquakes, there is a certain slow and quiet rise or sinking of the land over certain areas of the globe which takes place quite gradually and imperceptibly. These slow changes sometimes occur in volcanic districts, but they are also found in parts of the world where no volcanic or earthquake activity is known to have occurred.

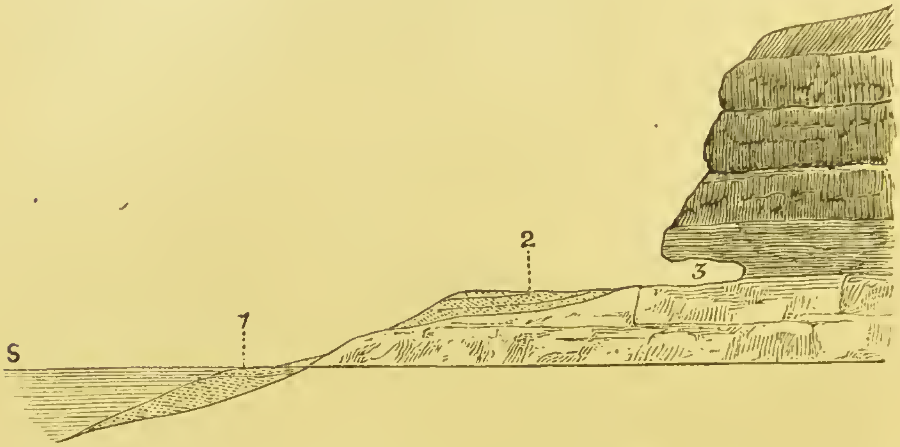
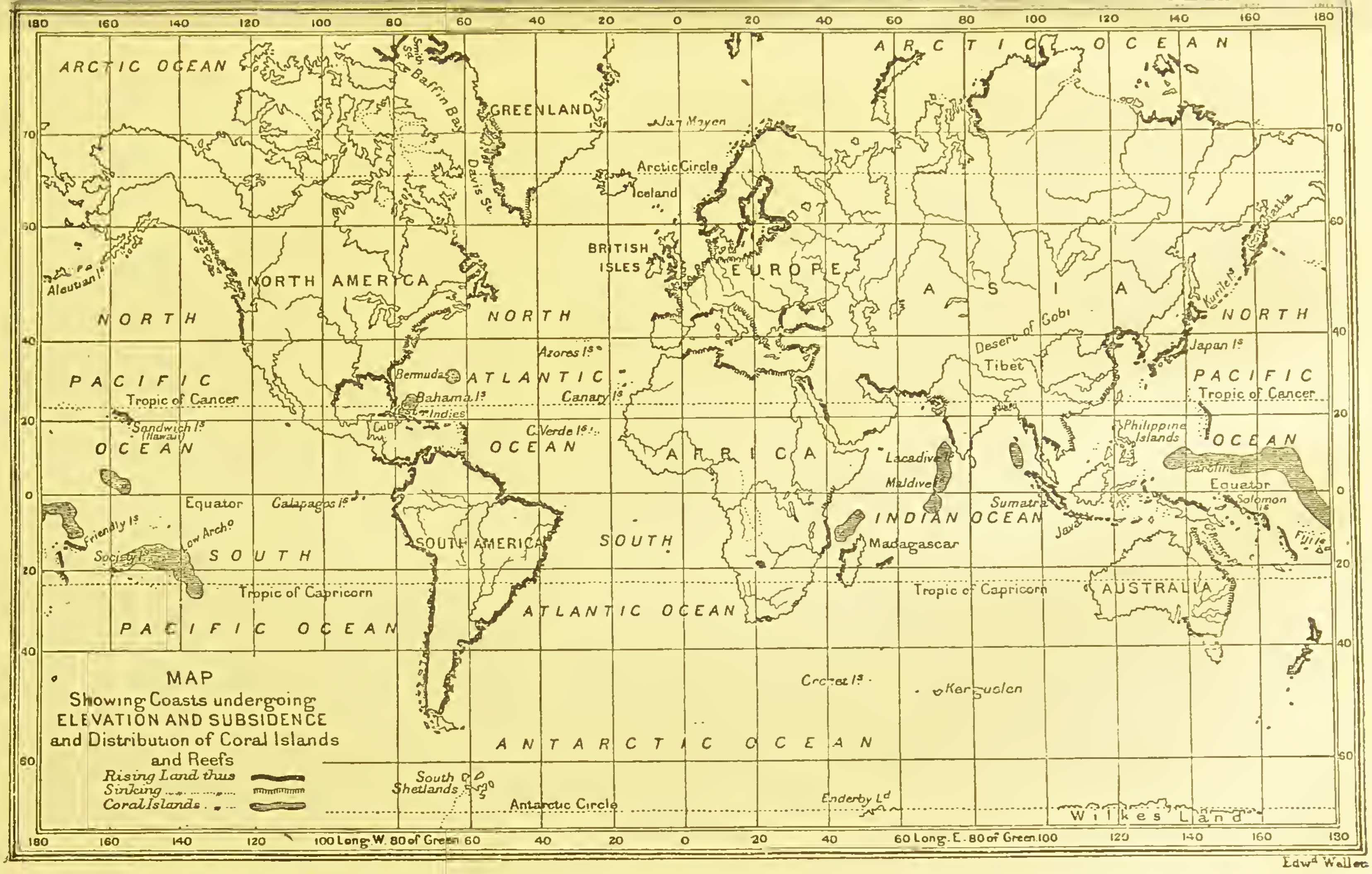


FIG. 57.—S, Present Sea-level at high tide. 1. Present Sea-beach. 2. Old Sea-beach. 3. Old Sea-cave.

173. **Signs and Proofs of Elevation.**—When land has been raised above the sea level, it generally brings with it some evidence of having been once under water. On the south and west shores of the island of Crete or Candia are seen the remains of docks and piers belonging to old Greek ports at an elevation of sixteen feet above the present sea level. On the Scandinavian peninsula in the Gulf of Bothnia marks were cut on the rocks by pilots in 1820, and these showed a rise of about four inches on being examined by Sir Charles Lyell in 1834. This shows an upward movement at the rate of about two and a half feet a century. But while the north of Scandinavia is slowly rising, the southern part is slowly subsiding. The evidence mentioned above refers only to historic times; but the existence of *marine shells* and *raised beaches* shows that these upward movements have been going on for vast ages. Parts of Tuscany and Sardinia have beds of shells at a height of 200 feet above the sea; while the harbours of Tunis are becoming too shallow for the approach of ships.


MAP
Showing Coasts undergoing
ELEVATION AND SUBSIDENCE
and Distribution of Coral Islands
and Reefs
Rising Land thus
Sinking
Coral Islands
ARCTIC OCEAN
ARCTIC OCEAN
GREENLAND
Smith Sd
Baffin Bay
Davis St.
Jan Mayen
Arctic Circle
Iceland
BRITISH ISLES
EUROPE
ASIA
Desert of Gobi
Tibet
Japan Is
Kurile Is
Kamschatka
Aleutian Is
NORTH AMERICA
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
Tropic of Cancer
Tropic of Cancer
Bermuda
Bahama Is
W. Indies
Cuba
Azores Is
Canary Is
C. Verde Is
Sandwich Is (Hawaii)
AFRICA
Lacadive
Maldive
Madagascar
INDIAN OCEAN
Sumatra
Java
Philippine Islands
Carolines
Equator
Equator
Solomon Is
Fiji Is
Gt Barrier R.
AUSTRALIA
Galapagos Is
Friendly Is
Low Archo
Society Is
SOUTH PACIFIC OCEAN
SOUTH AMERICA
SOUTH ATLANTIC OCEAN
Tropic of Capricorn
Tropic of Capricorn
Crozet Is
Kerguelen
ANTARCTIC OCEAN
South Shetlands
Antarctic Circle
Enderby Ld
Wilkes Land
100 Long. W. 80 of Green 60
60 Long. E. 80 of Green 100
Edwd Waller

MAP II

Raised sea beaches afford very satisfactory evidence of upheaval. On every sea-shore where there is a range of rocky cliffs a beach of sand and shingle is formed by the action of the waves, and caves are often hollowed out of the rock. If the land be raised, both the beach and the cliff are lifted up beyond the region of the waves, and a new beach is formed at a lower level. This may then be raised, and a third beach formed at a still lower level. Such a series of raised beaches occurs in several of the Norwegian fiords, on some parts of the South American coast, and in other countries.

Raised beaches are also found on the southern and western shores of England and on some parts of the Scottish coasts. In some cases the old sea-caves, as on the coast of Kintyre, form a range of natural rock-hewn compartments at a level of ten to thirty feet above the present tidal limits, and are perhaps the most convincing of all the various evidences of ancient sea action.

174. **Signs and Proofs of Subsidence.**—When land has sunk below the sea level the surface disappears from view, and the proofs are not so plain as in the case of elevation. But there is the evidence derived from the disappearance of human erections, from the existence of submerged forests, and according to Mr. Darwin from coral islands. It has been stated that the south and west shores of the island of Crete are rising, but the existence of remains of old Greek towns beneath the surface of the water on the eastern shore shows that this part of the island is sinking. In the southern part of Sweden the remains of houses, which were built of course above high-water level, are now buried beneath the water. The west coast of Greenland furnishes similar evidences of slow sinking. Submerged forests are found in some places where the land has slowly settled under favourable circumstances. These consist of stumps of trees still upright in the soil, often with beds of peaty matter, full of decaying roots, branches, and leaves. Such submerged forests are found on the coasts of Devon and Cornwall, and a large one exists near Hunstanton on the Norfolk coast.

CHAPTER VIII.

THE SEA.

175. THE entire surface of the globe is estimated at 197,000,000 of square miles, and of this a little more than one quarter, 52,000,000, is occupied by land; and nearly three-fourths, 145,000,000, is covered by water. The land consists mainly of two great masses known as the Old World and the New World, and it is evident from looking at a terrestrial globe that the great mass of this land is situated in the Northern Hemisphere, there being about three times as much land to the north of the equator as there is to the south of it. Though the waters of the ocean surround the land on every side, yet they are broken up into certain areas by the arrangement of the land portions, and to these various parts we give particular names.

(1) The Atlantic Ocean, lying between the western shores of Europe and Africa and the east coast of America.

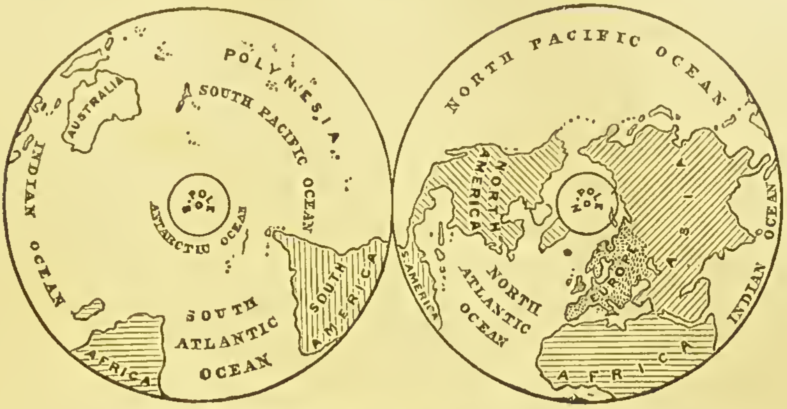


FIG. 58.—Northern and Southern Hemispheres.

(2) The Pacific Ocean, lying between the west coast of America and the east coast of Asia.

(3) The Indian Ocean, lying between the south of Asia and the Antarctic circle.

(4) The Arctic Ocean, lying within the Arctic circle.

(5) The Antarctic Ocean, lying within the Antarctic circle.

We know that our earth is a globe or sphere in shape. If we imagine it cut into halves by a plane passing through the two poles and the middle of the Atlantic on one side, and through the Pacific Ocean on the other, we call that half which lies to the west of England the Western Hemisphere, and the half that lies mainly to the east of where we live the Eastern Hemisphere. These two hemispheres may be seen in any atlas.

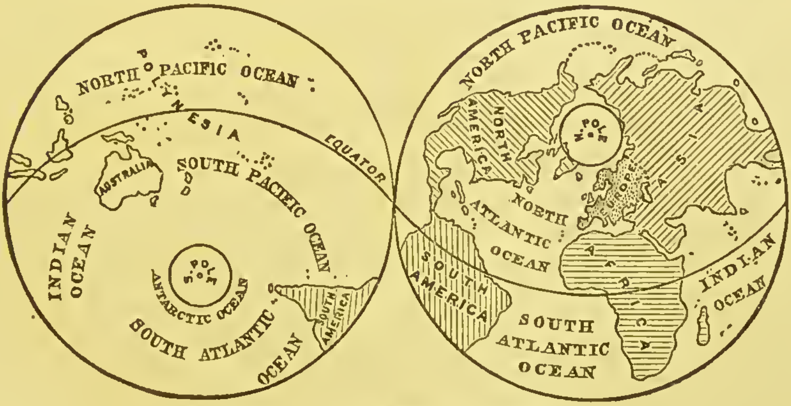


FIG. 59.—Land and Water Hemispheres.

But we may also suppose the globe to be divided into halves by a plane passing through the equator, and we should then get a Northern and Southern Hemisphere, a figure of which shows plainly the arrangement of land already referred to.

Again, the world may be supposed to be divided into halves by a plane perpendicular to a plane passing through the meridian of Greenwich, so that London is the centre of one hemisphere, and a point (Antipodes Island) in the ocean near New Zealand the centre of the other hemisphere. This shows us what may be called the Land and Water Hemispheres, as the one is mainly made up of land and the other mainly of water.

176. **Composition of Sea Water.**—The water of the ocean is not pure water, but contains dissolved in it various chemical substances known as salts. These salts amount in all to a little over 3½ grains in 100 grains of water; or, in other words, 3½ per cent. of sea water by weight consists of dissolved salts: chloride of sodium or common salt is the chief, forming 2·7 of the whole 3½ per cent. of saline ingredients.

The following table exhibits the exact per-centage composition of sea water.

One hundred parts by weight of sea water contain—

Water	96·470
Sodium chloride	2·700
Magnesium chloride	·360
Potassium chloride	·070
Magnesium sulphate	·230
Calcium sulphate	·140
Calcium carbonate	·003
Magnesium bromide	·002
Traces of iodides, silica, &c., estimated	·025
	100·000

Though the average proportion of salts is, as already stated, about three and a half parts in every hundred parts of water, yet there are slight variations.

In those seas which receive a large quantity of fresh water, and where there is little evaporation, as in the Baltic, the per-centage of dissolved matter is lessened; while in such seas as the Mediterranean, where evaporation is greater than the supply, the per-centage is increased. The highest per-centage found in the 'Challenger' expedition was 3·737 in water taken from the middle of the North Atlantic. The Red Sea, however, contains the saltest water, the per-centage of dissolved matter being 4·3. This is owing to the great evaporation always going on, and because no fresh water is poured into it, the supply of water being kept up by a current through the Straits of Babelmandeb. The presence of these dissolved substances is evident to the taste, for sea water is both salt and bitter. But the salts can be readily seen if a small portion of sea water is evaporated (see fig. 3). A number of crystals is then found in the basin, and on reference to the table of the composition of sea water it will be seen that common salt (NaCl) forms by far the largest portion of these soluble materials. Each of the substances has its own crystalline form, but the cubical crystals of common salt are the most abundant. In the south of Europe and other warm districts sea water is allowed to run into shallow beds, which are then shut off from the sea. As the water evaporates, a crust of salt forms on the margin, which is afterwards taken out.

177. **How the Sea became Salt.**—It is probable that the waters of the sea have been salt from the time that the earth became cool enough to allow the vapours of the atmosphere to condense and collect in the hollows of the surface. No doubt this original atmosphere had in it many saline vapours, and ever since this period the rivers and streams that flow from the land have carried in solution to the sea the various substances now found dissolved in it. As the water that evaporates from the sea is pure, the dissolved mineral matter being left behind, and as this water again falls on the land as rain, snow, &c., percolating through the rocks and dissolving such mineral matter as is soluble, it may be supposed that the saltness of the sea increases. There may be a very slight increase, but it must be remembered that there is a constant loss of this mineral matter in two ways. Some of it is carried back on to the surface of the land during storms and high winds, immense quantities of spray being often blown inland and carrying with it the dissolved salt. Another check to the increase of the saltness of the ocean is the requirements of the animals and vegetables that have their abode in it. The carbonate of lime ($CaCO_3$), and the calcium sulphate ($CaSO_4$), carried down in solution by rivers is the material out of which the hard parts of shell-fish, corals, foraminifera, &c., are built up. After their death these hard parts accumulate, and form the beds of limestone and chalk of which we have previously spoken. Silica (SiO_2), though existing in but minute quantity, 9 parts in 100,000 of water, is secreted by certain minute marine plants called *diatoms*, and minute animal forms called *Radiolaria*.[1] It may also be mentioned that sea water contains a certain amount of gases in solution, chiefly air and carbonic acid. The oxygen of this air is required by the animals that live in the ocean, and is constantly being renewed in the wind-tossed waves.

178. **Density or Specific Gravity of Sea Water.**—Compared with pure water, sea water is found to be slightly heavier; its *mean* density being 1·0275, that of pure water being 1. The salter the water is, the greater its specific gravity. Fresh water, being specifically lighter, floats on the surface for a time, but gradually becomes mixed with the heavier water beneath. It is owing to this that after a heavy rain, or at some distance from the mouth of a large river, fresh water may often be taken from the surface. As water is nearly incompressible, the density at various depths shows but very slight increase, though the pressure increases enormously. At a depth of 1,000 fathoms there is a pressure of about one ton to the square inch. Since the density depends chiefly on the amount of salts in solution, it is found that the specific gravity of the open ocean is greatest where the saltness is greatest. This occurs where there is great evaporation, and where we have winds constantly blowing over the surface, viz. in the trade-wind regions of the North and South Atlantic. As a rule the density diminishes from the surface to about 1,000 fathoms, and then increases again to the bottom. Near the coast where rivers enter the sea, and towards the poles where much rain falls, and ice and snow are continually melting, the specific gravity diminishes.

179. **Instruments of Research.**—*Depths of the Sea.*—Within the last few years much information has been gathered regarding the depth, temperature, and living forms of the ocean

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[1] It is probable that some of the silica is derived by these organisms from the fine clayey particles in suspension in sea water (see par. 187).

The English, American, Norwegian, and other Governments have sent out expeditions to explore the deep seas. The most important of these was the 'Challenger' expedition. The 'Challenger' was an English screw corvette which steamed away from Sheerness on December 7, 1872, and for three years and a half investigated the waters of the globe. During the first two years of the cruise Sir George Nares was in command of the ship, and he was succeeded at the end of that time by Captain Frank Thomson. During the whole time the scientific work was under the direction of Sir Wyville Thomson, assisted by Mr. John Murray and other men of science. We will now give a brief account of the methods followed on board such an exploring ship.

The depth of the ocean is found by the method of sounding. The ordinary method of sounding is to let down a weight with a line attached. This answers well enough in shallow water, but fails at great depths, because when the weight strikes the bottom cannot be learnt, as the line still continues to run out. After many experiments it was found that if a very heavy weight were attached, the sudden change in the rate indicated when the bottom was reached. But such a heavy weight could not be drawn up again, and Lieutenant Brooke contrived a simple means by which the weight or sinker should be detached on striking the bottom. This method has been still further improved upon, and the mode of sounding adopted by the 'Challenger' was as follows.

A block and pulley with 'accumulators' is fastened at the end of the ship's fore yard. These 'accumulators' are bands of india-rubber attached between two discs of wood for the purpose of breaking the strain on the sounding line. At the bottom of the accumulators another block is hooked with the sounding line rove through. To the end of the sounding line is attached the sounding rod or tube. The sounding line is marked at every 25 fathoms,[1] and lengths of 3,000 fathoms are kept on each reel. The sounding rod consists of a long cylinder of brass tubing about two inches in diameter, and fitted with a pair of butterfly valves at the lower end, opening inwards. The water that enters the lower end of the tube, while it is sinking, passes out through holes in the upper part. Round this tube sinkers of iron, each 56 lbs. in weight, are attached, 1 cwt. being usually allowed for each thousand fathoms. These sinkers are so fastened to the tube about 18 inches from its lower end that they are detached on reaching the bottom, and left there. Owing to the enormous pressure at great depths, it would be impossible to draw them up. It is known when they have reached the bottom and fallen off by the sudden change in the rate at which the line has been running out. On striking the bottom the sounding tube is forced into the mud, and the valve prevents the materials thus obtained from falling out. In this way not only is the depth at a particular place obtained, but specimens of the ocean floor are brought up. In Globigerina ooze the tube sinks eight or nine inches, and in clay about two feet.

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[1] 1 fathom = 6 feet; and 880 fathoms, or 1,760 yards, or 5,280 feet = 1 mile.

Figs. 60 and 61 give a view of two of the sounding rods used during the voyage of the 'Challenger,' with four weights or sinkers in position round the tube. These sinkers are cylindrical pieces of iron with a hole through the centre, through which the sounding tubes pass. They rest on an iron disc or washer, which is held in position by a wire fastened to an arrangement at the upper end of the rod, so that on reaching the bottom the wire is set free, and the sinkers slide off.

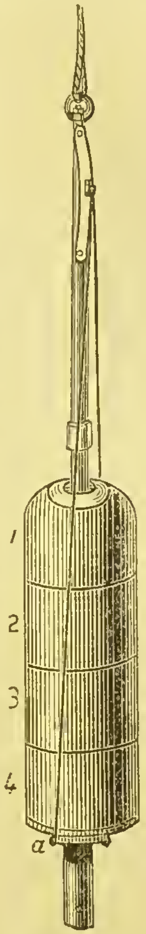


Fig. 60.
The Hydra
Sounding
Rod.

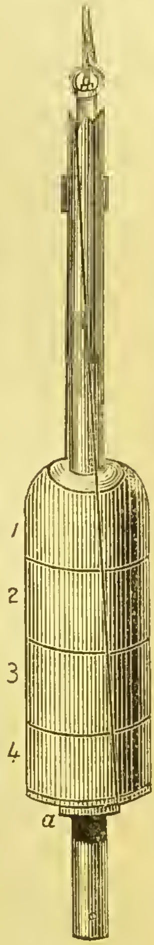


Fig. 61.
Baillie's
Sounding Rod.

But there are also other instruments attached to the sounding line when it is sent down. These are a specially constructed and protected self-registering thermometer to measure the temperature, a pressure gauge to register the pressure of the superincumbent column of water, and a water-bottle to bring up a specimen of water from the depth reached. The thermometer used in deep-sea sounding has to be specially constructed to resist the enormous pressure to which it is subjected. Hence the bulb which contains the mercury, or other fluid by whose expansion and contraction the temperature is measured, is enclosed in a strong glass case, so that its indications are not affected by the external pressure. Thermometers are sent down to different depths, and the temperature ascertained both at the surface and at various levels. The water-bottle is really a metal cylinder having a stopcock at each end connected by a rod, and so constructed that the water flows freely through it while descending, but when an upward movement begins the rod shuts the stopcocks and encloses a specimen of the water. On leaving the ship the sounding line with the instruments attached may be represented by the diagram (fig. 62, p. 102), though it should be noted that, through fear of damage from the motion of the ship, the sounding rods and sinkers were lowered into the water before the water-bottle and other instruments were attached. At first the line is let out slowly, but on reaching about 400 fathoms it is allowed to run out freely, the ship being kept over the place where the sinkers entered the water. The interval of time between the marking of every 100 fathoms is noted. These intervals gradually increase, owing to the sinkers being retarded in their descent by the friction of the increasing amount of line passing through the water. But the intervals are sufficiently regular to show that any sudden lengthening of the time indicates that the bottom has been reached. The bottom having been reached, the line is carefully drawn up by means of a donkey engine. When the thermometer, water-bottle, and sounding tube have reached the surface they are taken on board and detached from the line. The temperature indicated by the thermometer is read off and entered into a book; the water and the contents of the sounding tube are carefully preserved for examination.

For measurements where there was no reason to expect a depth of over 1,000 fathoms the ships used an ordinary deep-sea lead, fitted at its base so that an iron cylinder with a butterfly valve can be screwed on. The whole can be drawn up from such a depth.

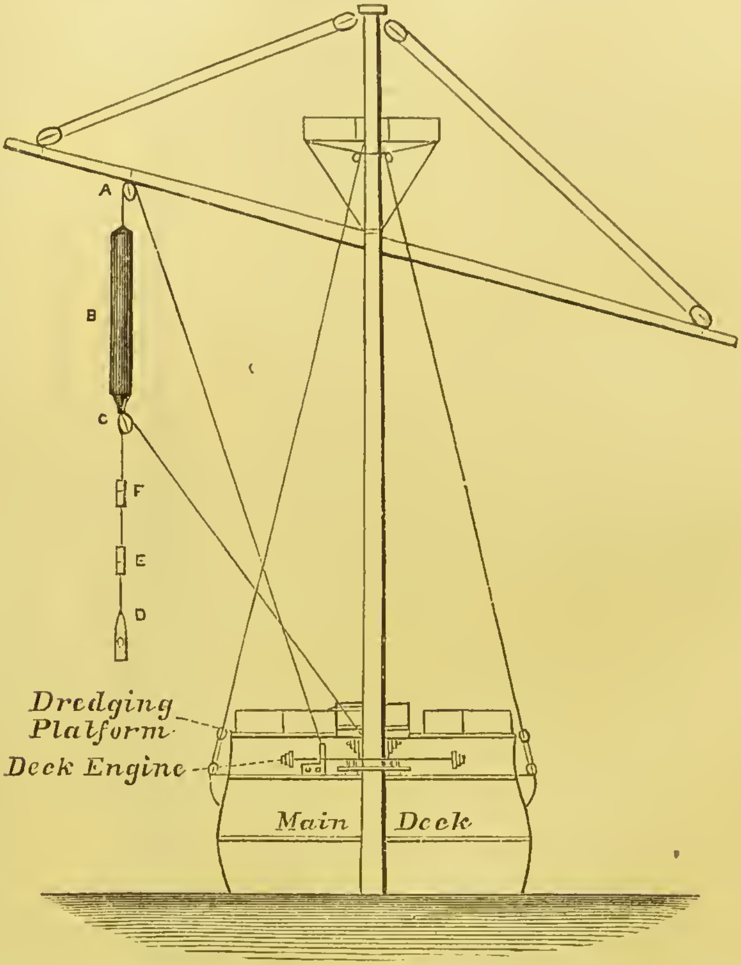


FIG. 62.—Diagram to illustrate method of sounding on board H.M.S. 'Challenger.' A, block secured to fore yard; B, accumulators; C, block through which sounding line passes; F, pressure gauge and thermometer. E, water-bottle; D, sounding rod and sinkers.

Dredging.—Besides the sounding apparatus, a dredge or trawl is also used to obtain specimens of the creatures living at various depths, or on the ocean's floor. During the latter part of the 'Challenger's' voyage a trawl of the ordinary shape was generally used. It consisted of a V-shaped net, one side of which was fastened by straps to a stout beam of oak, while the other side of the net hung loose.

180. **Depth and Form of the Ocean Floor.**—As a rule the sea is shal-

lowest near the land, though in a few cases there is a sudden descent to a great depth at a very short distance from the coast. Lowlands have usually shallow seas near the coast, and highlands deep water. Thus the seas around the British Islands are all comparatively shallow. The greatest depth in the German Ocean is about 100 fathoms, and in some parts, as the Dogger Bank off the northern coast of England, there are very shallow sand-banks; in the Irish Sea the depth is 40 fathoms, and at Dover Straits the depth is less than 30 fathoms. For about 100 miles, too, off the west coast of Ireland and Scotland the sea is comparatively shallow, and the

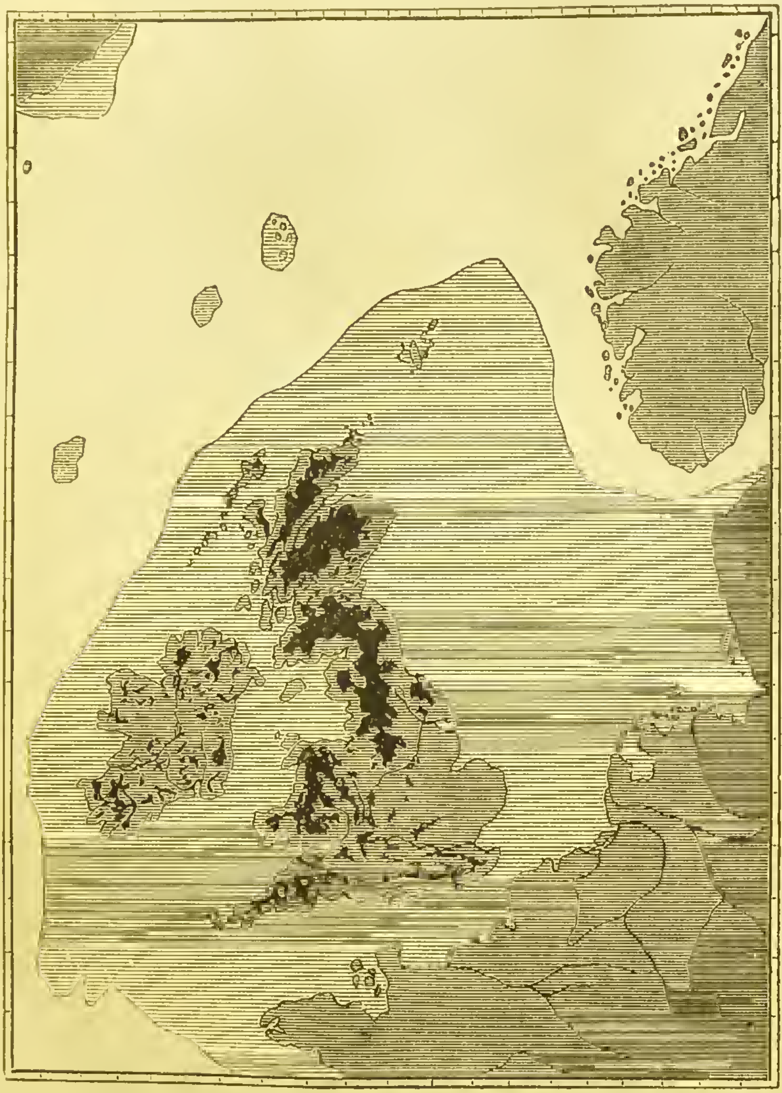
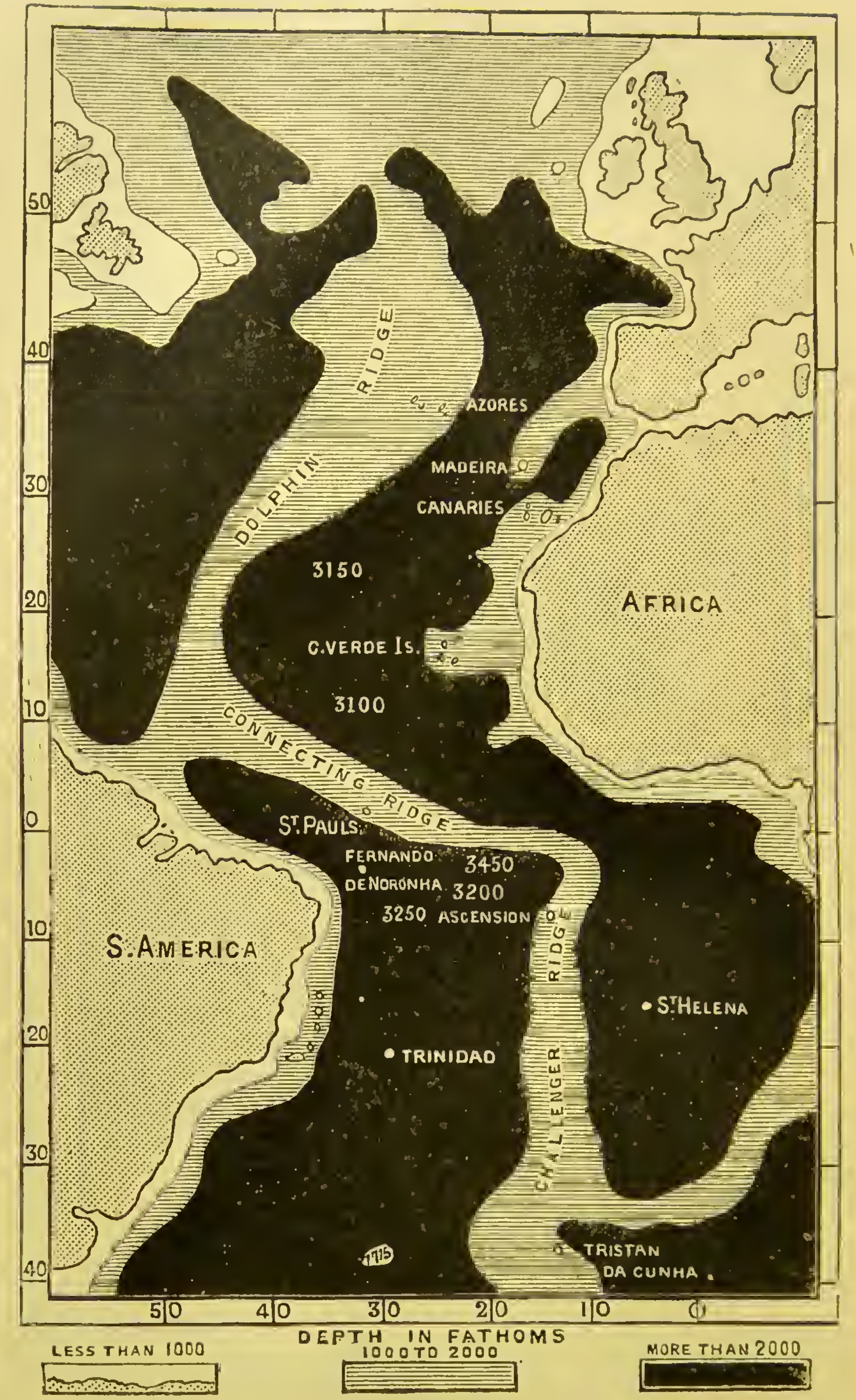


FIG. 63.—Sea-bed around Britain. The darkest shading indicates land above 600 feet high; the next shading shows the present outline of the land; the lightest shading indicates the sea floor at depths of 100 fathoms and less, and shows what would become land were the bed elevated this height.



Map III.—Atlantic Ocean, showing Depths.

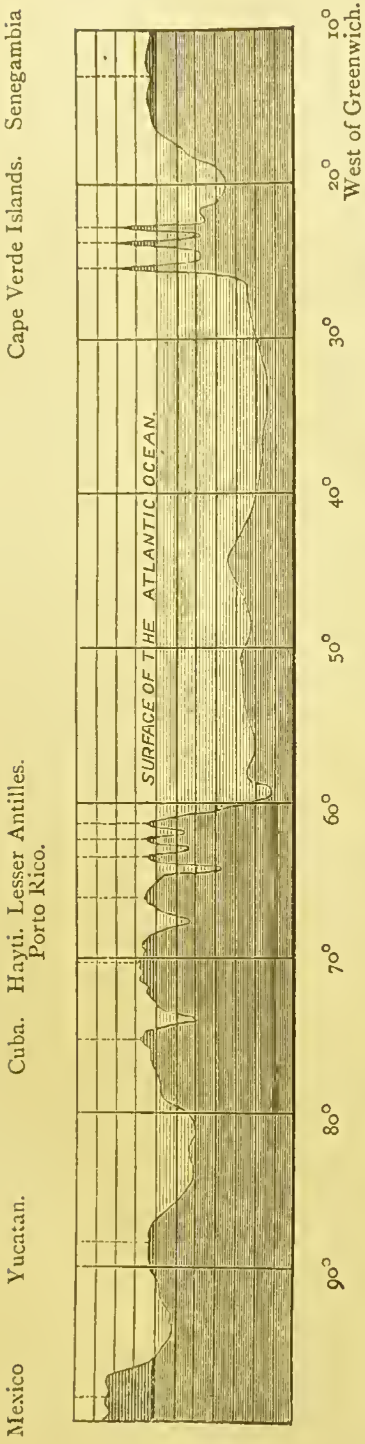


FIG. 64.—Section across the Atlantic Ocean between Senegambia and the Table-land of Mexico, 7,000 feet high. The greatest depth shown is about 17,000 feet.

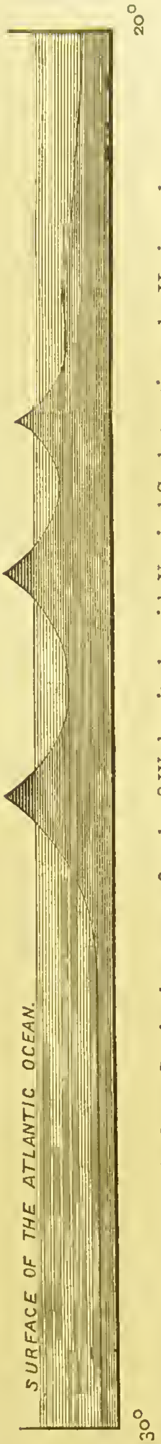


FIG. 65.—The Same Section between 20° and 30° W. longitude, with Vertical Scale ten times the Horizontal.

slope of the Atlantic but gentle. The British Islands are thus situated on a submerged plateau, and in all probability once formed part of the European continent, separated only from Norway by a gulf where the water is now 300 fathoms deep. In a similar way New Guinea is proved to have once been joined to Australia. From the plateau on which the British Islands are situated there is a rather rapid descent into deep water to a depth of about 12,000 feet. This stretches as a deep valley for hundreds of miles to the west, and ranges north and south almost parallel with the face of the Old World. A similar wide and deep valley is found to run parallel to the American coast, while between these two deep marine valleys rises a ridge which runs down the centre of the Atlantic. The upper surface of this central ridge is only about 10,000 feet below the surface, but the two great ocean valleys on each side of the ridge attain a depth of 18,000 feet. The accompanying Map III., p. 104, from Dr. Haughton's 'Lectures on Physical Geography,' shows the form of the bottom of the Atlantic Ocean. The unshaded portions are less than one geographical mile in depth—under 6,000 feet. The shaded portions are more than one mile and less than two miles in depth, between 6,000 and 12,000 feet. The black portions are more than 12,000 feet in depth. This map shows—

'(*a*) How closely the contour lines of 6,000 feet and 12,000 feet cling to the coasts of Africa and South America.

'(*b*) The remarkable central ridge ("Dolphin," "Connecting," and "Challenger") that divides the Atlantic into deep canals, keeping near Africa and South America respectively.

'(*c*) The islands of St. Helena, Trinidad, and Fernando de Noronha (especially the latter), rising abruptly from the deepest parts of the sea bottom.'

Another mode of illustrating the depth of the ocean is to show a section between two coasts. Fig. 64 is such a section between the coast of Africa and the coast of Central America. From this section we see that the West Indian islands shut off the deep waters of the Atlantic from the shallower basins of the Mexican Gulf and Caribbean Sea. But it must be borne in mind that in such a section the vertical scale is a great many times more than the horizontal scale. To guard against the false impression that may arise if this is not remembered, a small portion of this section which includes the Cape Verde Islands is repeated (fig. 65), though even here the vertical is ten times the horizontal.

On reference to the general map of ocean depths (Map IV. p. 107), which is shaded for depths different from those taken as the basis of shading in the Atlantic Ocean map, it will be seen that each of the deep valleys of the Atlantic contains still deeper abysses. One of these lies to the north-east of the West Indies; and here, at a distance of about 100 miles north of the island of St. Thomas, the 'Challenger' obtained a sounding of nearly 4½ miles. Since then the 'Tuscarora,' a United States vessel, obtained the still greater depth of 4,655 fathoms in the North-West Pacific.

The average depth of the Pacific Ocean has been estimated at between 15,000 and 18,000 feet, which is slightly greater than that of the Atlantic. The deeper portions may be learnt on reference to the map. The western portion of the North Pacific in particular shows some very deep depressions. To the east of Japan lies a long deep trough which in one part has furnished the sounding of nearly 5½ miles.[1] This is the deepest sounding yet obtained. South of the Ladrone Islands, in the Caroline Archipelago, there is also a deep abyss where the 'Challenger' obtained a sounding of nearly 27,000

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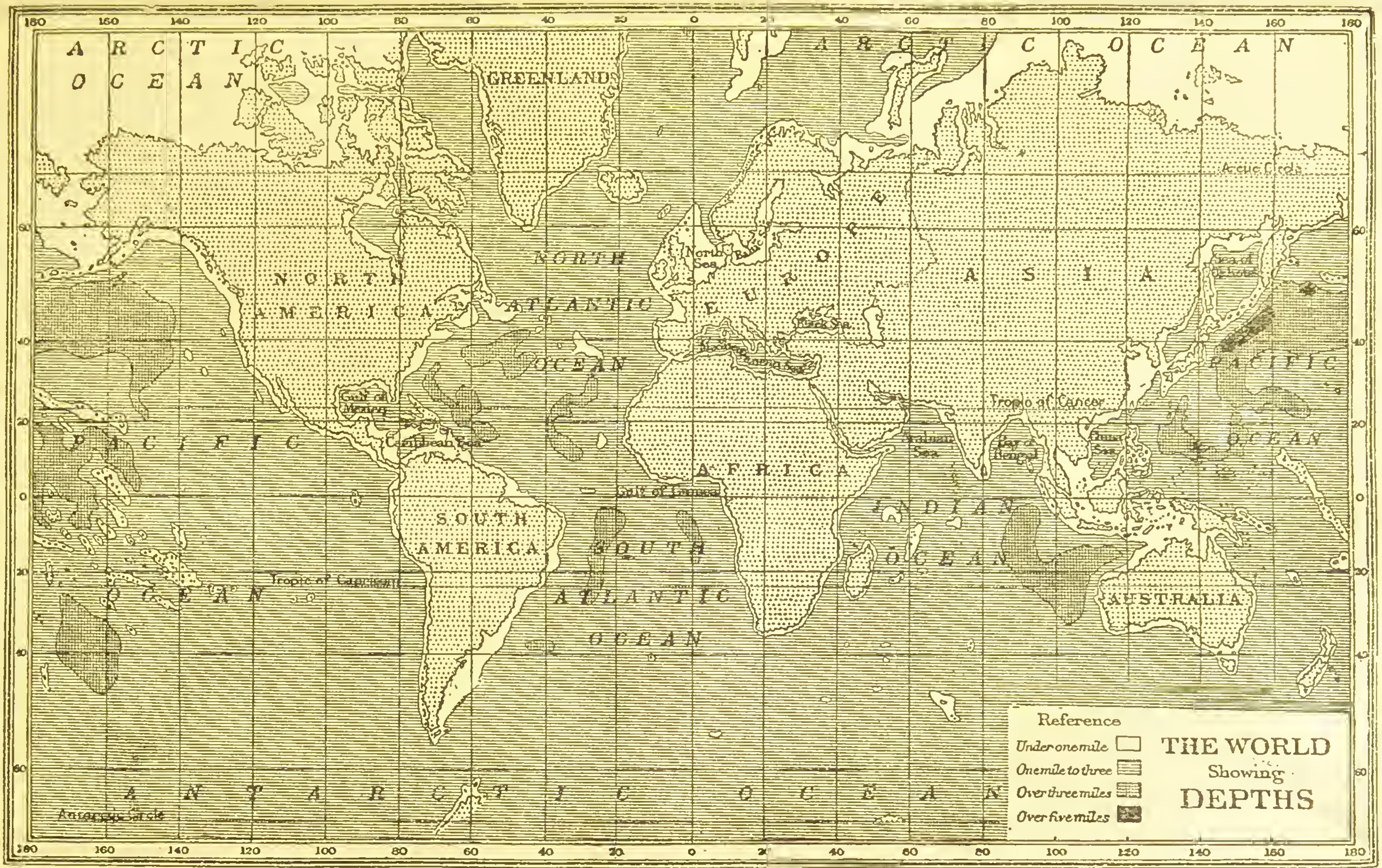
[1] This abyss is often called the Tuscarora Deep.



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MAP IV

feet. A submarine ridge connects the Friendly Islands, the Fiji Islands, and the New Hebrides.

In each ocean the greatest depths are in the Northern Hemisphere and towards the western border. Towards the north in the Northern Hemisphere the ocean rapidly becomes shallow. Between Great Britain and Iceland the depth is mostly under 6,000 feet, and in Behring's Straits the depth is only about 150 feet. The southern portions, however, of the great oceans are mostly of average depth.

The Indian Ocean has an average depth of about 12,000 feet, and the deepest soundings have been taken on the eastern side. The bed of the ocean has none of the steep ridges and jagged outlines of mountain scenery. There are great ocean plains where the ground is level; there are submarine peaks having steep descents; there are submarine plateaux often connecting together continents and islands; there are enormous valleys, and there are deep abysses reaching to five miles, and perhaps beyond. But in all cases the smoothing and rounding influence of the water has worn away the sharp edges so often seen on land, and has given to the steepest descents a roundness of curve and outline. It is interesting to observe that the deepest sounding, about 5½ miles, off the coast of Japan, nearly corresponds to the height of the highest mountain. Mount Everest has a height of 29,000 feet above the sea level. But it must also be noted that the mean height of the land, 1,000 feet, is only about one-twelfth the mean depth of the whole ocean, 12,000 feet. If as much land were carried into the ocean as would reduce the two to a common level, the ocean would still have a depth of about 10,000 feet. The average height of Europe, Asia, Africa, and South America is reckoned to be about 1,130 feet; of North America, 750 feet; and of Australia, 500 feet.

181. **Temperature of the Ocean.**—As already remarked, much information has lately been gathered respecting the temperature[1] of the sea at various depths by the researches made during the voyage of the 'Challenger' and other vessels sent out for scientific exploration. Thermometers protected from the outward pressure of the water are let down during the process of sounding to various depths, or several thermometers are fastened at intervals along the rope, and what are called serial temperatures are thus obtained. It must be remembered that the freezing-point of sea water is nearly five degrees below the freezing-point of pure water, and that, unlike fresh water, it contracts down to its freezing-point, thus becoming heavier the colder it gets. It should also be noted that land is more readily heated by the sun's rays than the waters of the sea, but it does not retain its heat so long. The water has a greater specific capacity for heat than the rocks forming the land; that is, it requires four times as much more heat to raise the temperature one degree than does the land. This greater amount of heat is given off as the temperature is lowered, so that warm currents of water may thus give up a considerable quantity of heat to overlying colder air. On the other hand, cold currents of water from polar regions may reduce the temperature of the overlying air. These currents of which we have just spoken will be treated of more fully in an Advanced Course. We must, however, point out that the great solar heat in the equatorial regions not only warms the waters in that part, causing them to become specifically lighter, but turns an enormous quantity into vapour. These causes produce a flow of the heavier colder water from the poles to the equator, and a

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[1] Temperatures are expressed in degrees Fahrenheit when not otherwise indicated.

contrary flow of the surface of the lighter and warmer water from the equator to the poles. The direction of these currents is greatly modified by the configuration of the coast, and the ridges in the bed of the sea. We shall afterwards prove the earth is a globe rotating on its axis from west to east, and carrying with it the waters of the ocean and the gases of the atmosphere. When, therefore, either water or air is transferred from one part of the globe to another, where the rate of motion is different, the direction of the water or air current becomes modified. In passing from the polar to the equatorial regions, where the rotatory speed is greater, such a current is drawn towards the west. A constant current flows from the cold Antarctic regions towards each of the great oceans. This forms in the South Atlantic what is called the equatorial current. On reaching the coast of Brazil the equatorial current divides into two branches, the northernmost of which passes through the Caribbean Sea into the Gulf of Mexico. Here, under the powerful rays of the tropical sun, its waters become heated, and it issues from the Straits of Florida as a mighty river, with a temperature more than 20° F. higher than the surrounding water of the North Atlantic. Assisted by the prevalent south-west winds, the surface drift of warm water from this stream is carried to the shores of Britain, and even of Spitzbergen. The cold current in the northern part of the Atlantic comes through Davis Strait along the coasts of Labrador and Newfoundland.

182. **Surface Temperature of the Sea.**—The temperature of the *surface* of the sea varies according to the latitude or distance from the equator, and also according to the seasons of the year, except in the equatorial regions, which are affected but little by change of season. Generally speaking, the surface of the ocean near the equator has an average temperature of about 80°, and this diminishes as we pass towards the regions of perpetual ice round the poles. The highest temperature is found about 6° N., and there the sea is usually warmer than the air. In the Northern Hemisphere there is a rise in the surface temperature of the sea in summer and a fall in winter, the epoch of highest surface temperature being in August, and that of lowest temperature in February—a month later than the corresponding turning-points in the temperature of the air. The same is true of the waters of the Southern Hemisphere—a rise in the *southern* summer and a fall in winter. The highest mean surface temperature is that of the southern part of the Red Sea, which is 90°.

Areas of high temperature from 84° to 85° are the China Sea, the Bay of Bengal, a district south of Sumatra, a portion of the Central Pacific, and the sea in the Gulf of Mexico to the Bahama Islands. Around Britain the temperature of the sea varies from about 49° in February to 60° in August. Owing to the existence of currents and other causes the lines of equal temperature in the temperate regions do not follow the parallels of latitude, though they correspond more closely in the case of the Pacific Ocean than in the case of the Atlantic. There is, however, never the same striking variation in the temperature of water at any place that there is in the case of air. Between the hottest and coldest part of the day there is seldom a difference exceeding one degree. The daily change in the temperature of the air over the sea is nearly four times greater than that of the water on which it rests.

183. **Deep Sea Temperatures.**—We may summarise the chief facts now known regarding the temperature of the deeper parts of the sea as follows:—

(*a*) In the open sea, far from coasts and barriers, a continual decrease of temperature from the surface takes place as the depth increases, quickly at first, and then more slowly, until at depths of 3,000 fathoms a temperature of about 35° F. is reached, and in still deeper areas a temperature as low as the freezing-point of fresh water, 32° F.

(*b*) The above is only true of the open sea, because where a submarine ridge exists, it retards the movements of the lower and colder waters, while the higher water passes over the ridge and fills up the area. Thus in the Sulu Sea the temperature falls rapidly from 80° at the surface to 50·5° at 400 fathoms, and this continues up to a depth of 2,500 fathoms. Hence this sea is apparently surrounded by a ridge separating it from the ocean depth. In the same way the shallow Strait of Gibraltar (200 fathoms) cuts the Mediterranean off from the general movements of the waters in the Atlantic, thus preventing the entrance of any cold polar water; and hence we find in this sea a constant temperature of about 54° at a depth beyond 100 fathoms. A similar explanation probably accounts for the finding of two such different temperatures as 29° and 43° at nearly the same depth between Scotland and the Faroe Islands.

(*c*) The layer of water at the bottom of which a temperature of 40° is found varies from 300 to 1,000 fathoms in thickness, and the great mass of ocean water lies below this layer (see fig. 66). This upper and comparatively thin layer of warm water is usually much thicker in the North Atlantic than in the South Atlantic, a fact probably due to the large influx of heated water brought by the Gulf Stream.

(*d*) The bottom temperature of the Pacific is on an average one degree lower than that of the Atlantic. In the North Pacific it was often below 35°, while in the South Pacific a temperature of 32·5° was found, and still further south (53° 55′ S. lat.) the thermometer registered 31° at a depth of 1,950 fathoms. In the Arctic seas the water has been observed warmer beneath than at the surface, though at the bottom and at the surface it may be below the freezing-point of fresh water.

(*e*) The temperature of the sea sinks more rapidly over shoals and shallows than in the open sea. The presence of cooler waters in these positions is probably caused by the colder deep layers being deflected upwards.

(*f*) 'All *inland* seas, at great depth, represent the mean temperature of the earth in the latitude where they are situated; whilst in the *ocean* the low temperature of the bottom in every latitude is produced by the cold currents setting in eternally from the polar regions.' These cold polar waters, having a higher specific gravity than the warmer surface waters, flow along the ocean floor towards the equator, the warmer and relatively lighter waters from the tropical regions flowing in the opposite direction. As the Arctic Sea is much less open to the Pacific and Atlantic (Behring's Strait is only 60 miles wide), it is thought that the greater part of the cold and dense water near the ocean floor is an indraught from the unconfined Antarctic seas.

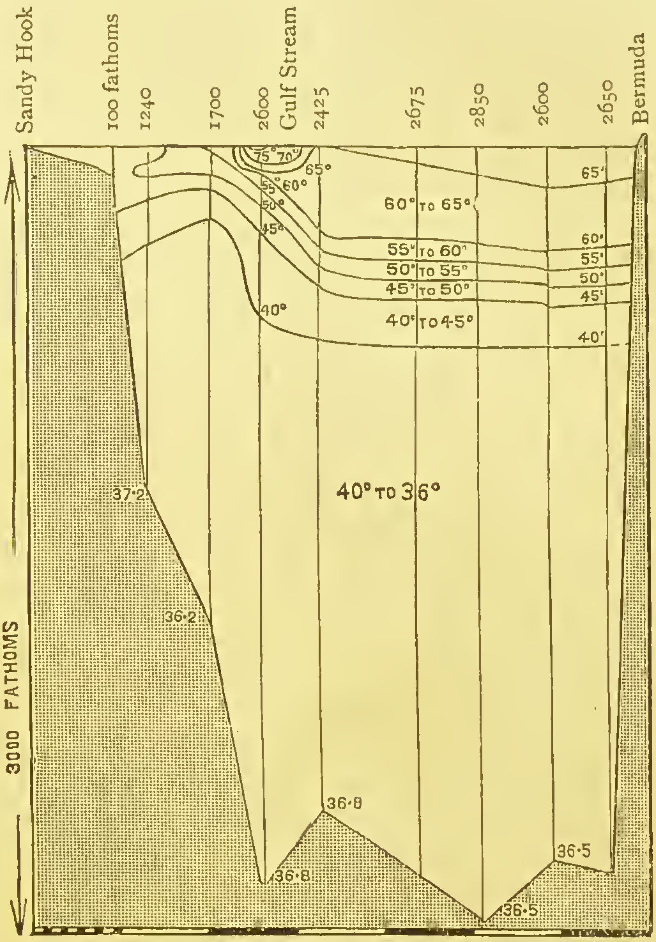

Fig. 66.—Diagonal Temperature Section between Bermuda and New York, showing the soundings and isotherms of the sea (curves of equal heat) obtained by the 'Challenger' in 1873.

184. The following diagram exhibits a series of temperatures and soundings taken in the Atlantic Ocean by the 'Challenger' between the island of Bermuda and the 100-fathom bank off New York. In this voyage the ship crossed what is called the Gulf Stream Delta at a distance of about 800 miles from where it leaves the Straits of Florida. On issuing from the straits the stream has a surface temperature of 80° F., and between Bermuda and New York the 'Challenger' found its surface temperature 75°, ten degrees higher than the water near Bermuda, and more than twenty degrees higher than the water of the cold current coming from Davis Strait along the American coast. But the warmest water is quite superficial. At 60 fathoms the temperature was 71°, at

80 fathoms 68°, at 100 fathoms 65°, at 125 fathoms 57°, and then it decreased rapidly to the bottom. 'It therefore appears that the Gulf Stream on May 1, 1873, in lat. 36° 23′ N., long. 71° 46′ W., was 15 miles in breadth, and about 100 fathoms in depth; that its speed was 3¼ miles per hour in a N. 60° E. direction; and that it was at that time discharging 4·87 cubic miles of water per hour into the North Atlantic basin, equal to 116·88 cubic miles per day, or 42,661 cubic miles per year. Taking into consideration the high specific heat of water, some idea may be formed of the vast amount of heat annually carried from the tropics into the North Atlantic. In the section from Bermuda towards New York eight soundings, seven temperature soundings, and four dredgings were obtained. The bottom temperature, at depths exceeding 1,800 fathoms, was again remarkably uniform, from 36·5° to 36·8°, the mean being 36·6°; nor was it affected in any way by the cold surface water on the north-west side of the Gulf Stream (see diagram). The isotherm of 40° was found at a uniform depth of 810 fathoms for 350 miles N.W. of Bermuda, but after crossing the Gulf Stream it rose to 280 fathoms. The other isotherms maintained a position parallel to that of 40°.' ('Challenger' Reports—'Narrative of the Cruise,' vol. i. p. 157.)

185. **Colour of the Ocean.**—Sailors sing of the 'deep blue sea,' and it is quite true that far from land and in considerable depths the sea possesses a pure bluish tint. Nearer the shore, however, the shallow water has a pale green tint, owing to the amount of suspended matter, the reflection from the sandy bottom mixing with the blue of the water. In some parts the varying colour is due to the numerous small seaweeds floating in it, or to the countless microscopic animals present. The vast quantity of yellowish muddy sediment brought down by the great Chinese rivers accounts for the name given to the Yellow Sea.

186. **Action of Sea on Earth's Crust.**—Wherever the sea-coast is fringed by hills, these are eaten into and gradually worn back by the action of the sea. The incessant action of the waves breaking against the shores, especially during storms, tears away and wears down the rocks, which often fall from the cliffs in immense masses.

This destruction goes on faster with the same kind of rock when the cliffs present a vertical face to the waves. Where the rocks dip seaward the action of the breakers falling on them is greatly diminished, as they roll up the slope with little opposition, and without doing much damage. In the end, however, with the aid of atmospheric agencies their disintegration is at last effected. Portions become detached, and roll down the rocky declivity into the seething water below.

This erosion of the coast is greatly assisted by the action of the rain and frost. The water getting between the fissures becomes frozen in the winter months, and the expansive force exerted during freezing widens the fissures and loosens the particles. The huge fragments thus broken off are caught up and hurled about by the waves. They are then broken up into smaller pieces, and the ceaseless roll of the waves wears off their sharp angles, and reduces them to the smooth rounded pebbles which form the gravel and shingle of many parts of the sea-shore. These undergo still further destruction, for in time the shingle is ground into sand, and the sand into mud. The finer this rock débris becomes, the further is it carried out to the sea by the action of the tides and currents.

In the annexed diagram we have the section of a cliff, the upper part of which is composed of a hard rock, such as sandstone, *a*, resting upon a softer rock, such as marl or clay, *b*. The action of the sea on the cliff would wear away the soft rock quickly, and so undermine the cliff as in time to cause masses of the hard rock to fall in a heap at the base, *c*. These for a time would protect the lower part from further destruction. But the action of the waves would eventually break them up and round them into *shingle*, *d*, and at last grind these into *sand*, carried further out at *e*. The finest particles of all,

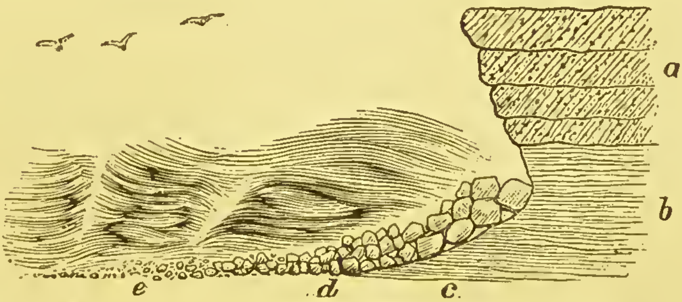

FIG. 67.—Action of the Sea on the Rocks of the Coast.

especially those derived from the softer rocks, would be carried out as *mud* to a still greater distance.

Those who have merely listened to the rolling pebbles on a sloping beach, watching the incoming wave hurl them up the slope and the retreating wave carry them rattling down again, can have no idea of the immense force exerted by the huge breakers striking an exposed ocean coast during a heavy gale of wind. On the west coast of Ireland, at Land's End in Cornwall, and among the Western Islands of Scotland, it is sometimes equal to about three tons on a square foot. Thus a surface of only two square yards might sustain a blow from a heavy Atlantic breaker equal to about fifty-four tons. In such situations the rocks are often scooped and hollowed out into the most fantastic forms. Portions somewhat harder, or more favourably situated, have better resisted the action of the waves, and these stand out as headlands, or detached portions, as 'needles' or 'stacks.' This unequal action on the harder and softer substance also gives rise to channels, creeks, and coves of every variety of form.

The destructive effect of the water of the sea is greatly aided by the boulders, pebbles, and sand which the waves toss about : just as the sediment carried in the waters of a running stream assists in grinding away the banks, so the sea uses the masses and shingle of the beach as instruments to pound and batter the cliffs of the shore.

We have thus seen how the sea is continually wearing away the land, and how rapid this destruction may be when the materials of the cliffs are but soft. The comparatively soft strata of chalk that form the sea cliffs of Kent and Sussex are worn away (when not protected) at an average of from one to two feet a year. The Isle of Sheppey has lost fifty acres of land in the space of about twenty years. On some of the eastern parts of the shores of England the crumbling clay that forms the sea cliffs suffers a loss of from one to three yards a year. Tynemouth Castle now stands at the edge of the sea, though a strip of land formerly intervened. The ancient sites of some former towns and villages, such as Auburn, Ravenspur, and Hyde on the Yorkshire coast, now lie buried beneath the sea. 'During the most violent gales the bottom of the sea is said by different authors to be disturbed to a depth of 300, 350, or even 500 feet, and Sir Henry de la Bêche remarks that when the depth is fifteen fathoms the water is very evidently discoloured by the action of the waves on the mud and sand of the bottom. But in the deep caves of ocean all is tranquil, all is still, and the most dreadful hurricanes that rage over the surface leave those mysterious recesses undisturbed.'

It must be noted that the sea is not eating away the land on every shore. In some parts are places sheltered from the action of the waves, and some shores have for a long distance seaward a level sandy beach, on which the waves spend their force without injuring the shore. In other places the sea, assisted by currents and winds, piles up ridges and hills of sand on the shore. Sea-shore sand consists of the water-worn particles of previously existing rocks reduced to small grains. It is partly brought down by rivers where it was held in mechanical suspension, and partly derived from cliffs on the sea-shore. The masses broken off the cliffs are first reduced to pebbles or shingle, and then, by the continual attrition of these produced by the rolling of the waves, they are reduced to small rounded grains. The most abundant material composing sand is quartz grains, but mixed with these there is often a quantity of calcareous material formed by the trituration of shells. Coral sand is derived mainly from the breaking up of coral rocks.

187. **Deposits on the Sea Floor.**—Messrs. Murray and Renard divide the deposits on the sea floor into (1) *terrigenous deposits*, or deposits derived from the wasting of the land, and carried down as sediment by the action of rivers, waves, and other movements of the water; and (2) *pelagic deposits*, or deposits found only in the deeper regions of the ocean basin.

The *terrigenous deposits* consist of (*a*) shore formations, blue mud, green mud and sand, red mud—found in inland seas and along the shores of continents; (*b*) volcanic mud and sand, coral mud and sand—found around oceanic islands and along the shores of some continents. The *pelagic deposits* include pteropod ooze, Globigerina ooze, diatom ooze, Radiolaria ooze, and red clay. (See Coloured Map, Frontispiece.)

As already remarked, the detritus or waste material produced by the action of the waves is deposited at no great distance from the shore, and shingle beds are not often met with at a distance of a mile from the coast. The finest particles of all are not carried further than 200 miles from the shore. These fine particles give rise to the *greenish* or *blue muds* so often found at depths of from 100 to 700 fathoms. This blue mud is the most extensive deposit now forming near the great continents and in large inland seas. Where large rivers enter the sea portions of the finest material may be carried to still greater distances. These deposits, now forming near the shores of continents and large islands within 200 miles of the shore, resemble in all respects the sedimentary rocks of which we have spoken, and may at some distant period form the chalks, sandstones, shales, and conglomerates of future land. In the deeper parts of the ocean very different deposits are found. North of lat. 50° S., at depths varying from 250 to 2,900 fathoms, a fine, light-coloured ooze or silt called *Globigerina ooze* is found. It consists chiefly of the minute calcareous shells of Globigerinæ and other Foraminifera mixed with some silicious shells of Radiolaria. At greater depths this 'modern chalk of the Atlantic' passes into red clay. In some places the calcareous ooze consists of the thin transparent shells of another class of animals (molluscs), called *Pteropods*. *Radiolarian ooze* is a deposit met with in the Western and Middle Pacific. It consists of minute perforated silicious shells, formed by tiny creatures called Radiolaria, that live in all zones, and secrete silica for their skeletons. *Diatom* *ooze* consists of the flinty frustules or cells of diatoms, tiny *plants* that live on the surface, and after death sink to the bottom. These microscopic cells or valves are found in areas of great depth far from land. *Red* and *chocolate clays* form the chief deposit at the greatest depths. These are mostly of volcanic origin, and are probably produced by the volcanic dust carried by the winds, or from the decomposition of the pumice-stone borne by the waves. The colour is mainly due to the presence of iron and manganese oxides. Mixed with these clays, especially in the South Pacific, great numbers of sharks' teeth and the hard compact ear-bones of whales were brought up by the dredge.

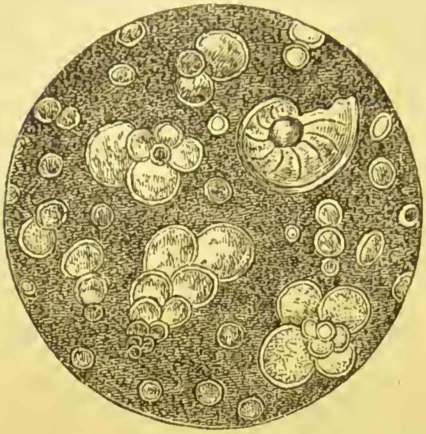

FIG. 68.—Section of Gravesend Chalk, showing shells of Foraminifera (highly magnified).

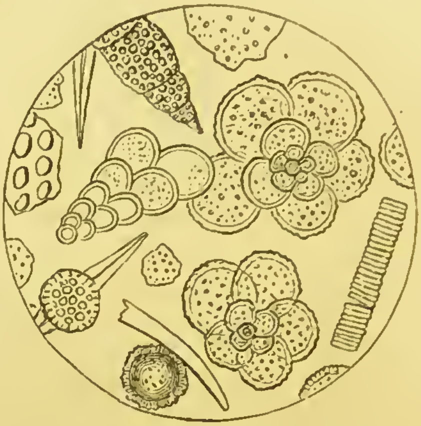

FIG. 69.—Organisms in Atlantic Ooze, chiefly Foraminifera, with a few Radiolaria and sponge spicules (highly magnified).

The following fuller account is derived from the 'Challenger' Report on Deep-sea Deposits :—

Marine deposits are classified as follows :—

Deep-sea deposits beyond 100 fathoms.	Red clay.	**Pelagic deposits** formed in deep waters far away from land.
	Radiolarian ooze.	
	Diatom ooze.	
	Globigerina ooze.	
	Pteropod ooze.	
	Blue mud.	**Terrigenous deposits** formed in deep and shallow water close to land masses.
	Red mud.	
	Green mud.	
	Volcanic mud.	
	Coral mud.	
Shallow-water deposits between low-water mark and 100 fathoms.	Sands, gravels, muds, etc.	
Littoral deposits between high and low water marks.	Sands, gravels, muds, etc.	

Average depth at which each of the more important deposits is found, percentage of $CaCO_3$, and area of distribution—

	Mean depth in fathoms	Mean percentage of $CaCO_3$	Area in square miles
Red clay	2,730	6·70	51,500,000
Radiolarian ooze	2,894	4·01	2,290,000
Diatom ooze	1,477	22·96	10,880,000
Globigerina ooze	1,996	64·53	49,520,000
Pteropod ooze	1,044	79·26	400,000
Coral mud	740	86·41	2,556,800
Coral sand	176		
Other terrigenous deposits	8	19·20	16,050,000
Shallow-water deposits	—	—	10,000,000

Red clay is a stiff clay of a deep brown or red colour, found in the deep parts of the ocean beyond 2300 fathoms, and far from land. It is especially abundant in the Central Pacific and the deeper parts of the Atlantic, its colour being due mainly to the oxide of iron, or, when chocolate, to the oxide of manganese. It consists of the residue of dissolved calcareous organisms, siliceous remains, water-logged and disintegrated pumice and wind-borne volcanic dust. Hydrated silicate of alumina often constitutes one-half of the deposit, and the calcium carbonate in the deepest parts does not exceed 2 per cent. The colour is due to the presence of oxides of iron and manganese formed from the decomposing volcanic material. These oxides also form deposits around any hard **nucleus**, and **manganese nodules** so formed, or manganese-iron nodules, as they are more correctly termed, varying in size from a marble to an apple, are found abundantly in red clay. They occur as concretions forming concentric zones of manganese hydrate around sharks' teeth, ear-bones of whales, fragments of pumice, etc. Whether the manganese is derived from the decomposing volcanic rock or from the sea water, is doubtful. Besides the mineral particles derived from disintegrating pumice, red clay contains particles of Secondary origin belonging to the class zeolites, and formed *in situ* by chemical changes from the materials in the clay. Particles of cosmic or extra-terrestrial origin are also met with in red clay. These are black and brown spherules which can be attracted by a magnet. The black spherules are about $\frac{1}{12}$ inch in diameter, have an external crust of magnetic oxide of iron, and a nucleus of iron or iron alloyed with cobalt and nickel. The brown spherules are about $\frac{1}{6}$ inch in diameter, formed of the mineral enstatite, and have a peculiar radiated lamellar structure, similar to that found in meteorites.

The presence of vertebrate remains belonging to extinct species, the formation of manganese nodules, and crystals of zeolites, and the occurrence of metallic and stony chondroi of cosmic origin, all prove that red clay accumulates at a very slow rate.

The small percentage of calcium carbonate in the red clay and other deep deposits is due to the solution of the calcareous shells of the pteropods and foraminifera (that live near the surface) as they sink, on the death of the animals, through the great depth of sea water containing some carbonic acid. Pteropod ooze is not met with beyond 1500 fathoms, and Globigerina ooze disappears beyond a depth of 2500 fathoms.

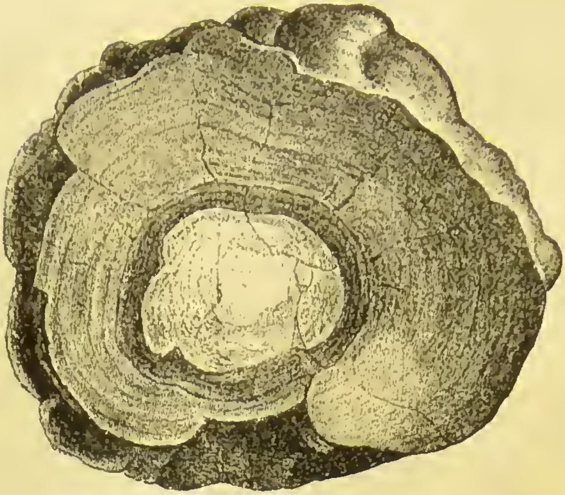

FIG. 70.—Section of Manganese-iron Nodule (natural size) from South Pacific (2550 fathoms). A light nucleus, probably of volcanic origin, is seen surrounded by darker layers of hydrated manganese oxide, akin to bog manganese ore.

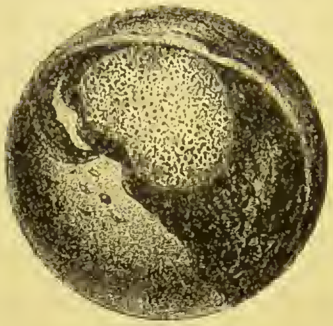

FIG. 71.—Cosmic Magnetic Spherule from 2375 fathoms. The crust of magnetic iron oxide has been broken through to show the metallic nucleus of native iron or alloy of iron (magnified 90 diameters).

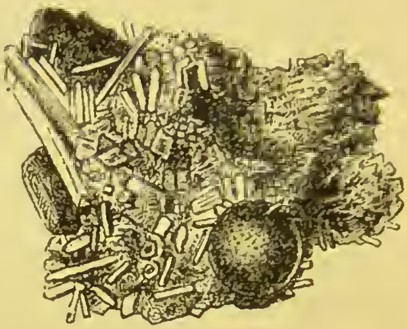

FIG. 72.—A Cosmic Spherule attached to a mass of little crystals of zeolites formed in the abyss from other minerals (magnified 90 diameters).

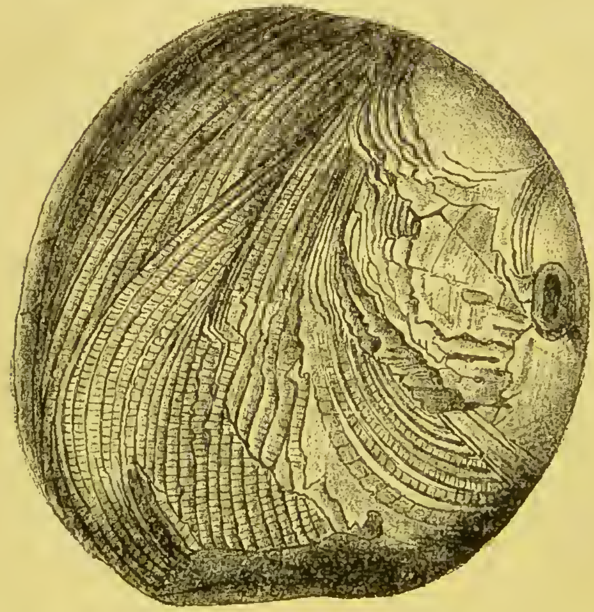

FIG. 73.—Chondre or Spherule of Bronzite, a variety of the mineral enstatite, showing a leafy radial structure. Like the cosmic spherules, it is probably a portion of the dust of meteorites that have fallen in the course of ages into the deep sea (from 2000 fathoms; magnified 37 diameters).

Radiolarian ooze is the name given to the ooze that contains 25 per cent. or more of the siliceous shells of these minute animals. It is found in some of the deeper parts of the Central Pacific and Indian Oceans, where radiolarians abound on the surface, but it is not found in the Atlantic. This ooze is the same in composition as the red clay, with the addition of siliceous shells and spicules. Silica is not nearly so soluble in sea water as calcium carbonate, and hence siliceous remains, as radiolarian shells, sponge spicules, and frustules of diatoms, are found at great depths.

Diatom ooze is composed in large part (40 to 50 per cent.) of the siliceous frustules of diatoms. It is a distinctive deposit of the southern ocean, within the limits of the Antarctic ice drift. When wet it has a creamy colour, and when dry looks like flour. Fragments of granite, sandstone, and other terrigenous mineral matter is often met with in this ooze. Diatom ooze has been found also in the North Pacific. Both radiolaria and diatoms obtain their silica from the slight quantity in solution in the sea water, and probably also from the fine clayey mud in suspension.

Globigerina ooze is a deposit containing from 30 to 90 per cent. of the calcareous shells of foraminifera (those of the genus Globigerina being most abundant), with an admixture of mineral particles and siliceous shells. These animals live in the surface and sub-surface waters of the ocean in countless millions, and on their death their shells fall in myriads on the bottom of the sea. Foraminifera are small specks of jelly-like material that build up chambered shells of calcium carbonate. In Globigerina the walls are pierced by minute apertures, and delicate spines project from the outer surface. Near the land the shells become covered with deposits from the land (terrigenous deposits), and in the deepest parts the shells are dissolved before reaching the bottom by the agency of the CO_2 in sea water. But between 500 and 2500 fathoms this ooze is found covering nearly 50,000,000 square miles of ocean floor, and it is especially abundant within the tropics. Seen under the microscope, many of the tiny shells of Globigerina ooze are found to closely resemble those of chalk. The carbonate of lime ($CaCO_3$) can be secreted from any calcium salt, the animal itself supplying the CO_2; and there is so little $CaCO_3$ in sea water that calcium sulphate, $CaSO_4$, is probably the chief source of supply.

Pteropod ooze consists of the delicate shells of surface-living molluscs, especially pteropods, that live in the tropical seas. It is not found below 1000 fathoms, and only covers about 400,000 square miles in the Atlantic.

Very small organisms, consisting of plants allied to seaweeds (Algæ) and termed **Coccospheres** and **Rhabdospheres**, live in the surface waters of tropical and temperate regions, and secrete discs or rods of calcium carbonate on their surfaces. Hence these coccospheres and rhabdospheres are found mixed with the other ingredients of the last two oozes.

Blue mud is the most extensive of the land-derived deposits found in deep water. It is found along the coasts of continents and continental islands, and in some enclosed seas up to distances of 100 to 200 miles from land, though Congo and Amazon mud have been found 500 miles from the shore. Blue mud consists of the fine sediment carried out by rivers with a varying proportion of sand and other mineral particles, as mica, felspar, etc., and some marine organisms. The material carried out to sea by rivers is about thirty-three times as much as that worn from land by waves, tides, and currents. The blue or slaty colour is mainly due to the presence of sulphides formed out of sulphates by the reducing action of decomposing organic matter. Ferric oxide is also reduced to ferrous oxide, though in

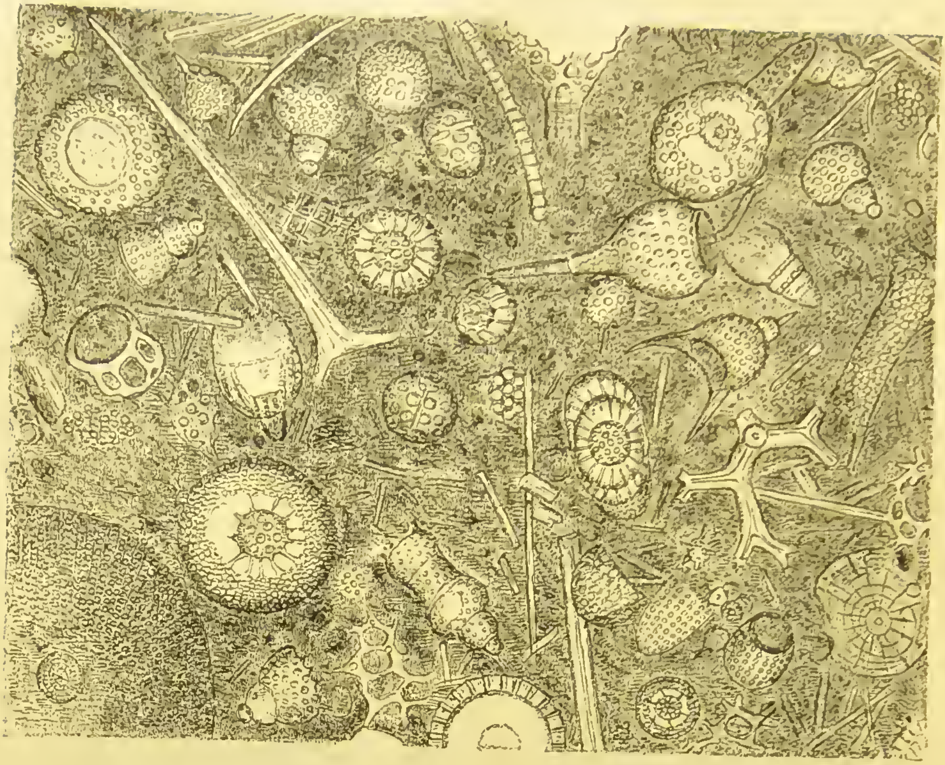

FIG. 74.—Radiolarian Ooze dredged from a depth of 4475 fathoms in the Western Pacific. Shells of radiolaria and siliceous sponge spicules are seen.

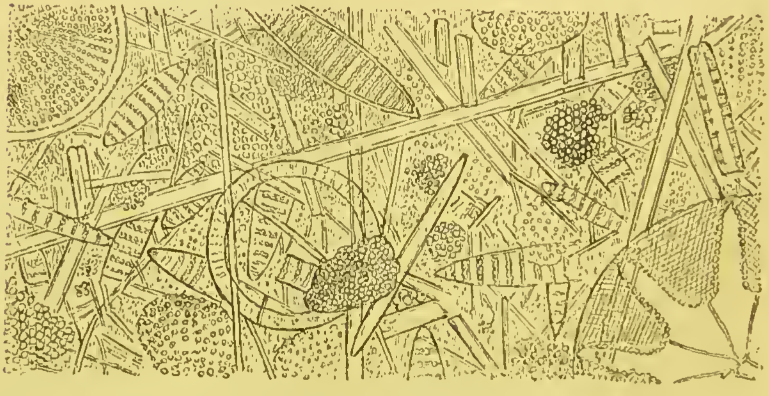

FIG. 75.—Section of Diatom Ooze, from 1950 fathoms (Indian Ocean). The frustules of diatoms are shown with Globigerina shells (magnified 300 diameters).

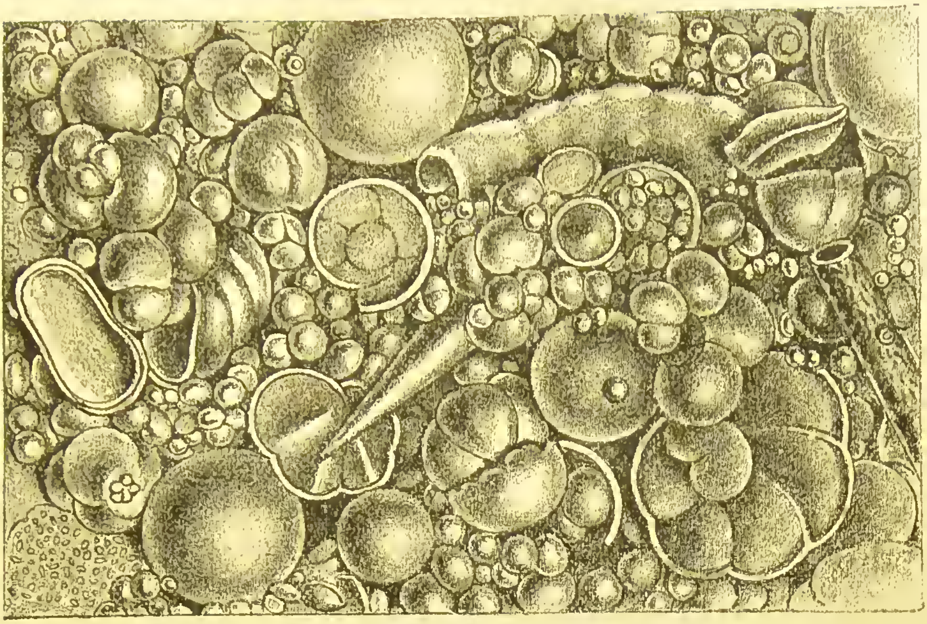

FIG. 76.—Globigerina Ooze from North Atlantic (1900 fathoms). It consists chiefly of the shells of various foraminifera (magnified 25 diameters).

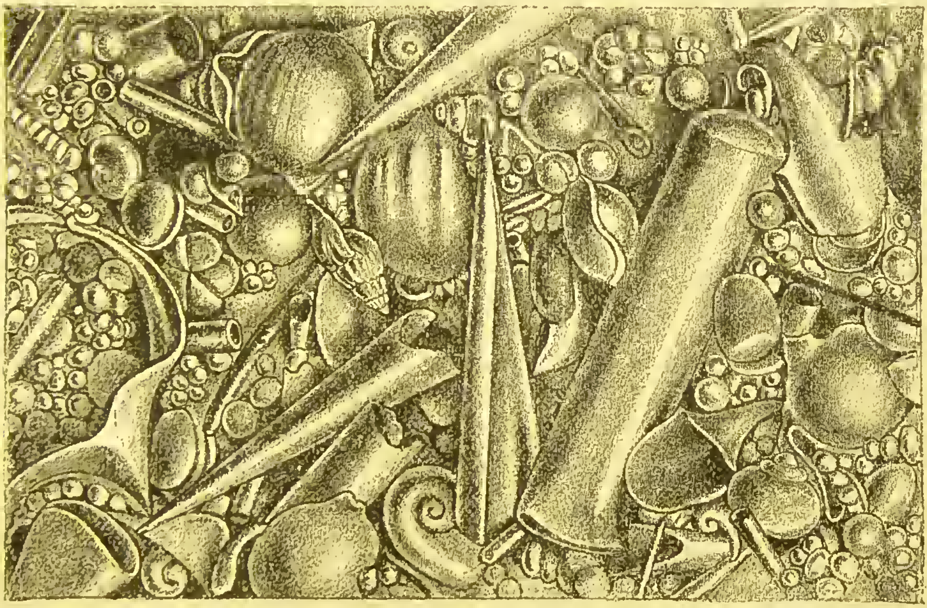

FIG. 77.—Pteropod Ooze from 450 fathoms. Pteropod and other molluscan shells, with shells of foraminifera.

some cases the ferric oxide is so abundant that the deposit is known as red mud.

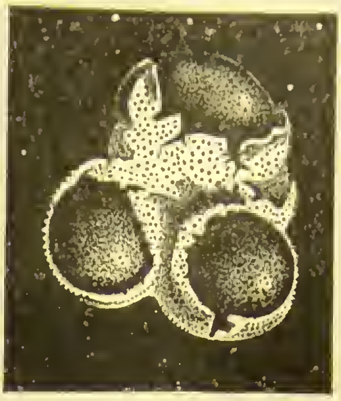

FIG. 78.—Glauconite Grains in shell of Globigerina. The grains are green.

Green mud takes the place of blue mud off steep coasts without great rivers, as the south of Africa, south of Australia, and west of North America. It contains a greenish mineral called **Glauconite**, which is a hydrated silicate of iron, potassium, and aluminium. The glauconite appears as grains or concretions, and is often found filling the shells of foraminifera. It appears, indeed, to be formed, in the first instance, in the shells of calcareous organisms by chemical changes that begin in the ocean bed.

Volcanic mud and sand are found deposited around volcanic islands and shores. The deposits consist of fragments of igneous rocks such as are ejected by volcanoes, the deposits getting finer and more mixed with pelagic organisms as the distance from the shore increases. In course of time sea water effects chemical changes in some of these rocks. The finest particles from a volcanic eruption may, indeed, be carried all over the globe, as in the case of the eruption of Krakatoa. Pumice-stone, being so porous, floats for months, and drifts long distances before it becomes waterlogged and sinks.

Coral mud and **sand** are found around coral islands and reefs. It consists of calcium carbonate with remains of marine organisms. For examples of 'Challenger' soundings, see Appendix, p. 305.

188. **Ocean Currents.**—The Gulf Stream may be regarded as a branch of the Equatorial Current which flows across the Atlantic from the west coast of Africa to the east coast of Brazil, and which is produced mainly by winds blowing in the same direction. (Currents are named, unlike winds, according to the direction in which they flow.)

On reaching the coast of Brazil this westerly Equatorial Current divides into two branches—one flowing south, and called the Brazil current; the other passing northward into the Carribean Sea and Gulf of Mexico. This second branch, deflected by the land to the north-east, leaves the Mexican Gulf for the most part between Cuba and Florida as a rapid warm current of deep blue water, called the Gulf Stream (par. 184). It then passes northwards parallel to the American coast, acquires a more easterly direction off Cape Hatteras, and, passing over the southern end of the Newfoundland bank, terminates in the North Atlantic as a distinct current about longitude 35° W. In its course its velocity, which is at first about 4 miles an hour, becomes less; its breadth gradually expands; its temperature decreases; and it becomes shallower. Though ceasing as a distinct stream about the middle of the North Atlantic, some of its surface waters are carried, as the 'Gulf Stream drift,' by the prevailing south-westerly winds to the shores of Great Britain and Iceland (see par. 260 for its influence on our climate). A portion of the stream, however, returns southward along the coast of Portugal and Brazil, while in the area of the Atlantic around which the currents flow lies the Sargasso Sea, the surface of which is thickly strewn with a floating seaweed (see Map X.).

A cold current from the Arctic Seas, known as the Labrador Current, passes southward between the Gulf Stream and the coast of the United States, the line of separation between the two currents being known as the "cold wall." A part of the great Equatorial Current of the Pacific, corresponding to the Gulf Stream, and flowing along the east coast of Asia, is known by the Japanese name of 'Kuro Siwo,' or 'Dark Stream.' A fuller account of ocean currents is given in the 'Advanced Physiography.'

CHAPTER IX.

THE POLAR REGIONS AND THE ICE OF THE SEA.

189. **Arctic Ocean.**—The Arctic Ocean includes that portion of the sea surrounding the north pole, and bounded on the south by the northern coasts of Europe, Asia, and America. It does not therefore exactly coincide with the Arctic circle, which is 23½° from the pole, as it reaches further south at the north of the Old World, and at the North Cape where it joins the Atlantic. With the Atlantic it has two gateways of communication, the wide opening between Norway and Greenland, and the narrower passages through Davis Strait between Greenland and the great archipelago of islands on the north of America. With the Pacific it has only a narrow connection of sixty miles at Behring Strait. The passage between the Atlantic and Pacific along the ice-encumbered channels between the islands on the northern shores of America is called the 'North-west Passage,' and was once much sought after as a route to India and the East. The passage along the northern shores of Europe and Asia through Behring Strait is called the 'North-east Passage.' This circular basin included within the above limits is but very partially known. From the parallel of 72° north, which skirts its southern land limit, up to the parallel of 80° it has been often explored, but only a few expeditions have proceeded farther north. This is on account of the sea beyond being so blocked with ice that ships are not able to make progress. In 1875 Sir George Nares reached the latitude of 82° 10′ N. in H.M.S. 'Alert,' and from that ship a sledge party

under Commander Markham succeeded in planting the British flag in latitude 83° 20′ 26″ N., 400 miles from the pole. Instead of finding the 'open polar sea,' the ice was found to be of most unusual age and thickness, and to this region the name *Palæocrystic Sea*, or sea of ancient ice, has been given. Owing to the absence of land trending northward, and the polar pack not being navigable, Sir George Nares concluded that no ship could be carried north on either side of Smith's Sound beyond the position they had attained. Since then Lieutenant Greely has made a slight advance further north.

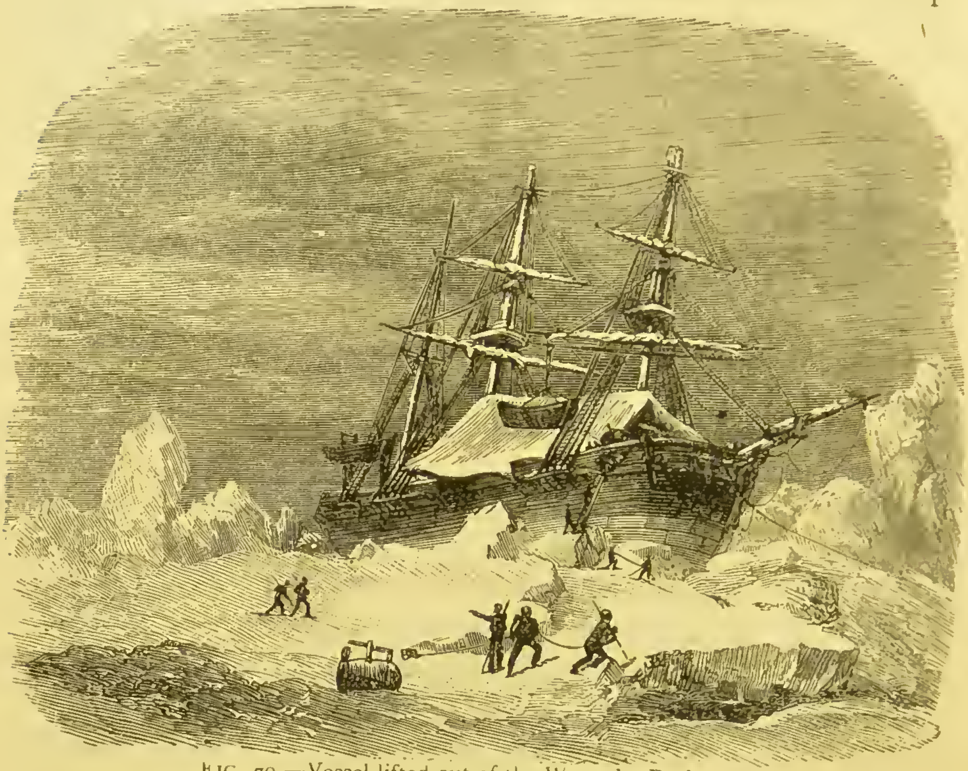

FIG. 79.—Vessel lifted out of the Water by Pack Ice.

The floor of the Arctic Ocean does not much exceed 1,000 fathoms in depth, and at the point reached by the British expedition was only 72 fathoms.

190. **Marine Ice.**—On approaching the ice of the polar regions its presence is indicated to the mariner by a brilliant band of yellowish-white light along the horizon called the *ice-blink.* The ice-blink is produced by the reflection of the light from the snow-covered ice. The ice of the Arctic seas is of two different kinds, the one being formed in the sea, and the other coming from the surface of land. The intense cold of the

Arctic winter freezes the water on the surface of the sea, but the restless movements of the waves seldom allow a thick covering of level ice to be formed, large stretches having an uneven surface being produced. Such an expanse of marine ice having no visible limit is called an *ice-field.* An ice-field, then, does not consist of a level sheet, but is an immense irregular expanse, having deep hollows and large mounds called 'hummocks,' or hills, and is often interspersed with fissures, which are sometimes filled with drifted snow. In the winter this frozen sea is kept within its narrowest limits, but at the beginning of summer the ice-field, which may be continuous for hundreds of miles, begins to break up, the smaller detached portions of a field being called *floes,* and a number of floes closely compacted together is known as *pack ice.* It is this pack ice which so often forms a barrier impassable to ships even in summer, though at times it opens out into channels through which a bold adventurer steers. In 1806 Captain Scoresby forced his way through 250 miles of pack ice until he reached the latitude of 81° 50′ N. A pack is sometimes broken up into loose masses called *drift ice.* The ice-fields detached from the frozen seas during the summer are carried forwards by waves and currents, and sometimes crash together with such force as to produce a scene of terrible grandeur, huge floes being broken off at the edges, and an enormous pile of fragments being squeezed together into a mass.

Many a good ship has been crumpled up like matchwood or lifted bodily on to the ice by such an icy embrace. In 1869 the 'Hansa,' a German exploring vessel, was so damaged by the pressure of the ice on the east coast of Greenland that she sank. The crew with their boats and provisions established themselves on an ice-floe about two miles in diameter. For 200 days they resided on this drifting mass surrounded by other floes, and were carried southwards during the summer by the currents for a distance of 1,300 miles. At this time the floe had diminished greatly in size, but fortunately an opportunity of escape to the coast then presented itself.

191. **The Ice-foot.**—There is still another form of sea ice. This is formed by the sea freezing along the margin of the land, so that a layer lifted up by the tide becomes frozen to the shore. Such a shelf of ice formed along a shore, as on the edge of North Greenland and other islands, is called the *ice-foot* (fig. 80). The ice formed by the freezing of the Arctic seas seldom exceeds seven or eight feet in thickness, but on the coast it rises in long rugged ridges to a height of thirty or forty feet. This shore ice not only carries loose débris attached underneath, but often receives a mass of stones and rubbish from the overhanging cliffs. Much of this ice-foot may remain attached to the shores for years, but during the warmth of summer the loose bergs and floes driving against it sometimes detach large masses, which float away with their load of materials. These are either carried until the ice melts and deposits its cargo of blocks and rubbish, or the floating raft of ice from the ice-belt becomes caught again in the ice of the succeeding winter.

192. **Frozen Sea Water contains Very Little Salt.**—During the process of freezing the sea water throws out nearly all the salts it contains, so that the ice when thawed furnishes fresh water which can be drunk.

Weyprecht observes, 'When the growth of ice is carried on quickly in times of intense cold a great number of crystals are formed, whose salt particles are not only drawn downwards in the water, but scattered round on all sides. In consequence of this the original melted ice consists of crystals loosely adhering together, and mixed with the solution of salt which has been rejected from them all. As the ice grows harder by the freezing together of the separate ice crystals, this solution also freezes with them in its upper strata. When the latter has attained a certain degree of thickness the further formation of the lower strata progresses only very slowly. The addition of fresh ice crystals from belows goes on regularly, but in their formation the salt is almost all carried downwards into the sea.'

193. **Icebergs.**—But besides the various forms of marine ice just described, there are found in the Arctic seas huge masses of ice called icebergs. These have been derived from the surface of the land in the Arctic regions, and, having been pushed down to the sea, have floated away. Nearly the whole surface of Greenland is covered with an ice-sheet which advances towards the sea, the rate of motion of the Greenland glaciers being much greater than that of Alpine glaciers, nearly 100 feet a day in summer and 30 to 35 feet a day in winter. Here immense fragments are broken off and carried by the waves and currents towards the south. The ice breaks off from one of these Arctic glaciers either by being pushed along the bottom of the sea till it reaches such a depth that, being lighter than water, it is broken away by the upward pressure of the water, or by coming at once into deep water, when the mass is snapped off by its own weight. Fig. 81 explains the origin of icebergs by the extension of a polar glacier seaward.

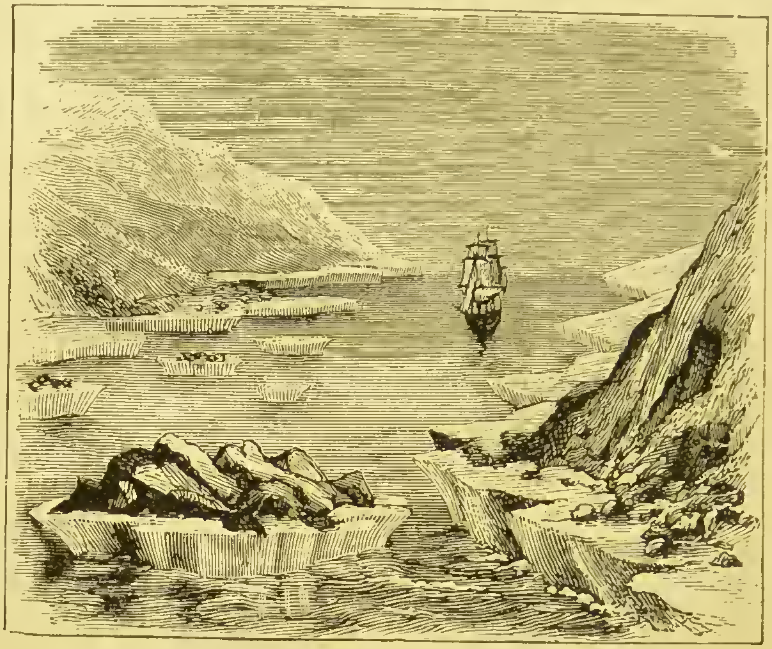

FIG. 80.—Ice-foot.

Some of the largest icebergs are found in Davis Straits, and are often of enormous size. They carry boulders and smaller pieces of rock derived from the land over which they have passed, and floating southwards they often reach as far as the coast of Newfoundland. Here they melt away and deposit their load of stony rubbish on the bottom of the sea. At times icebergs from the west coast of Greenland have been known to reach latitude 36° N. before they were melted, but owing to the warm waters of the Gulf Stream the bergs from the east coast of Greenland do not reach nearly so far south. It must be noticed that an ice-floe, being a mass of marine formation, bears no transported blocks, as icebergs do, except it be derived from the ice-foot. These floating mountains of ice drifted by polar currents constitute a source of great danger to the steamers approaching the American shores from England. Owing to the coldness of the air produced by so great a mass of ice the vapour in this air is often condensed into a fog, so that the berg is only visible at a short distance.

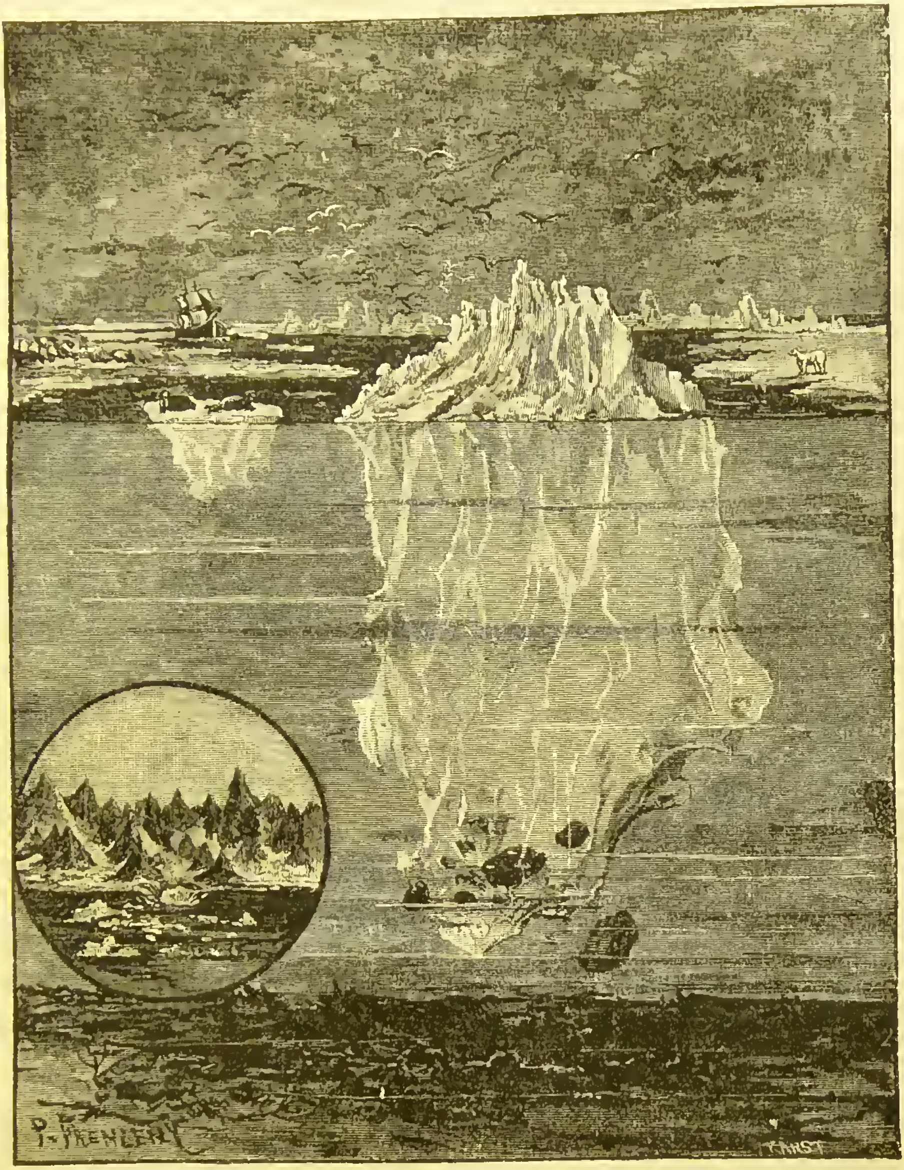

Fig. 81. A Scene in the Arctic Regions, showing a Floating Iceberg.
(By permission of Messrs. Barne & Co.)

Not only do icebergs scatter boulders and gravel over the floor of the sea, but they often ground in shallow water, furrowing and grinding up the sea bed. In this way large masses of seaweed may be loosened and sent floating away. The large number of grounded bergs on the coast of Labrador gives rise to almost continuous chill fogs during the summer. The visible portion of a berg is only a fraction of what is below water. The specific gravity of ice is about ·92, and the specific gravity of sea water nearly 1·03. The ice being thus lighter than water floats, but being only a little lighter the greater portion is submerged, only about one-ninth of the bulk being above water. As, however, the ice often encloses bubbles of air, a greater fraction than this may often be allowed. The actual *height* above and *depth* below water depend to some extent on the shape of the berg. The Arctic bergs are of all sizes, and often of the most fantastic shapes. Dr. Hayes measured one which stood 315 feet out of water, and was over three-quarters of a mile in length. Assuming that only one-seventh was above the water, such a berg would have gone aground at a depth of about half a mile. Being continually acted on by the waves and the warmth, the floating bergs often fall to pieces, or, becoming top-heavy, fall over, causing great turmoil in the sea.

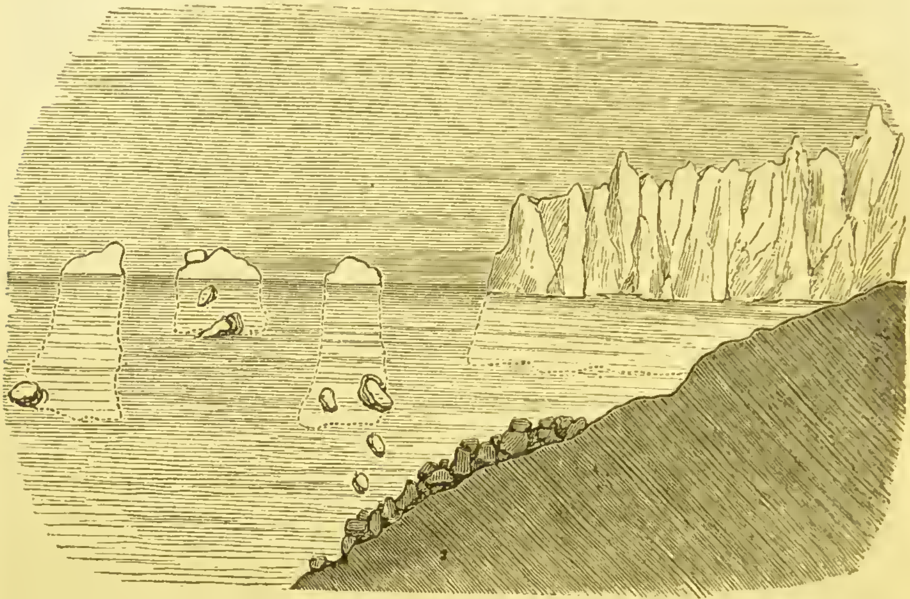

FIG. 82.—Diagram Section of an Arctic Glacier giving off Icebergs.

194. The following remarks by C. R. Markham, Esq., the President of the Royal Geographical Society, furnish a useful summary of the terms used in describing the ice found in the Arctic seas.

'Sea water in the process of congelation expels the salt, and its freezing-point is about 28° Fahrenheit. The ice first forms in thin irregular flakes, called "sludge," and when this is compact enough to hold snow it is known as "brash." Gathered into rounded masses it becomes "pancake ice," and soon it becomes thicker. The first thin covering is called by the whalers "bay ice." A "floe" is a sheet of ice the limits of which are visible. An "ice-field" differs from a floe in being so extensive that its limits cannot be seen. "Pack ice" consists of broken floes forced together by the winds or currents. When the pack is loosened and scattered by a wind from an opposite direction the pieces are called "sailing ice." The greatest thickness attainable by ice in one season is about 7 feet. The results of observations made by Sir George Nares in 82° 17′ N. on the west side of Greenland, and by Captain Koldewey on the east side in 74° 30′ N., were identical, viz. 6 feet 7 in. Old ice is believed to become thicker in a second winter, and even to attain a thickness of 10 feet In the Palæocrystic Sea there are floes from 80 to 100 feet thick, but these must be considered rather as sea glaciers, formed by accumulations of snow on the ice year after year, and the smaller pieces broken from them have been very appropriately named "floebergs." These mighty floes are sea-borne glaciers, perpetually wasted beneath and restored from above. Icebergs are only met with where there are great discharging glaciers on the land or in the currents leading from them. Greenland is the principal mother of icebergs. This immense mass covers an area of about 512,000 square miles, and has 34,000 miles of coast-line. It is indented by deep channels or fjords, often extending more than 60 miles, with many islands and rocks along the coast. The whole of the interior is believed to be capped by an enormous glacier always moving towards the coast, and at certain points reaching the sea, where masses break off in the shape of icebergs. These icebergs rise to a height of 60 to 300 feet above the sea, with a circumference from several hundred to several thousand yards; and from seven to eight times the bulk seen above water is submerged, so that the weight of a large berg is millions of tons. When pieces break off from a parent iceberg the process is called "calving," and the pieces are "calf ice." Recent observations of one of the principal discharging glaciers show it to be 920 feet thick and 184,000 feet wide, and that it advances at a rate of 47 feet a day during the summer season. In Spitzbergen and Nova Zembla there are much smaller glaciers, discharging smaller berg pieces. The Franz-Josef Land glaciers produce large flat-topped icebergs, which do not, however, float southwards.'—*Encycl. Brit.*

195. **Antarctic Ocean.**—The Antarctic Ocean includes the great body of water within the Antarctic Circle, and is a continuation to the south of the Atlantic, Pacific, and Indian Oceans. Compared with the district round the north pole, the south polar regions are but little known. This is partly owing to the great severity of the climate, for its temperature is generally lower than that of the corresponding latitudes of Arctic regions. South of 62½° S. lat. the temperature of both air and water is almost constantly below freezing-point even in summer. The greatest known tract of land is the line of coast stretching between the parallels of 70° and 78° S., and lying between the meridians of 160° and 167° E. long. It was called Victoria Land in 1841 by its discoverer, Sir James Ross. Ross succeeded in reaching the highest latitude yet attained in the southern seas, 78° 10′ S. His progress was then stopped by an icy barrier nearly 200 feet high, along which he sailed for 300 miles. On this land a mountain chain was seen, in which an active volcano, 12,000 feet high, was observed. To this volcano the name 'Erebus' was given, after one of the ships; while an extinct volcano to the east of this was called 'Terror,' after the second

ship. Another explorer, named Wilkes, discovered land in 1839 between the parallels of 65° and 67° S., and extending from the 100th to the 160th meridian of east longitude. Other portions have been sighted by various navigators.

How far the land stretches is not known; but from the swarms of icebergs that are found, from the continental character of the deposits found on the sea floor, and from the diminution in the depth of the sea bed on going further south, it has been inferred that the parts observed are merely the outer portions of a large island continent surrounding the pole. Between 64° and 66° S. lat., the most southern latitude reached by the 'Challenger,' depths of 1,675, 1,800, and 1,300 fathoms were obtained; but Ross found a depth of only 260 fathoms further south, near the icy cliffs of the barrier. This Antarctic land, however, is almost inaccessible, as it is completely icebound. Only two explorers have actually landed within the Antarctic Circle, though many have seen land. But the ice in the vicinity so blocks up all approach to the coast and hides the shore, that it is difficult to say where the land begins. In some parts a line of icy cliffs 150 to 200 feet high, and called the 'Ice Barrier,' runs along the coast, rendering it impossible to land, whilst in other places there stretches a solid mass of ice pushed off the land, rising 5 or 6 feet above the surface, and going probably to a depth of about 40 or 45 feet below. Ross saw both these kinds of ice, the ice cliffs and the land ice, and he states that the ice cliffs ('Ice Barrier') are not found where the land is high and mountainous.

196. **Antarctic Icebergs.**—Most of the icebergs met with in the south polar region are *tabular flat-topped bergs*, and are probably derived from the icy barrier already mentioned. They are often bounded by almost perpendicular sides, showing one or two stories of upright cliffs with crevasses, and having little hillocks of drifted snow on their flat tops. The entire mass shows a well-marked stratification, being composed of alternate layers of white opaque-looking, and blue more compact and transparent ice. The general mass is described as having the appearance of loaf sugar, with a slight bluish tint, excepting where fresh snow resting on the top and ledges is absolutely white.

The colouring of the crevasses, caves, and hollows is said to be a pure azure blue, so that these southern bergs are magnificent sights. The Antarctic bergs also differ from those given off by Arctic glaciers in seldom bearing any visible rocks, stones, or dirt on their surface, though it is probable that, in the lower parts of the bergs under water, gravel and other débris may be present. They are also met with several degrees nearer the equator than the north polar icebergs, being carried by the flow called the Antarctic Drift Current. Generally speaking, the limits are 35° S. lat. and 40° N. lat. (See Map VIII.)

197. **Antarctic Temperatures.**—In the month of February, in lat. 64° 37′ S., during the southern summer the temperature of the surface water obtained by the 'Challenger' was 32° F., that of the air being 30°. At a depth of 100 fathoms a temperature of 29·2° was obtained, but at 300 fathoms the temperature rose to 33°. The bottom temperature at 1,800 fathoms was between 33° and 29°. This comparatively warm water at a depth of 300 fathoms has doubtless flown southwards from lower latitudes to replace the ice and cold surface water drifted northward in summer. In the Arctic Ocean there is kept up a freer circulation than in the Antarctic, for the warm drift from the Gulf Stream passes into it between Scandinavia

and Greenland, and this is partly compensated by the cold current passing through Davis Strait and bringing with it a large portion of the winter's ice. 'A circulation similar to this appears to be entirely wanting in the Antarctic regions; hence their icebound character.'

CHAPTER X.

THE ATMOSPHERE.

198. Surrounding the crust of the earth on all sides, and reaching far above the summits of the mountains as well as filling the deepest cavities, there is a vast invisible ocean of gas or vapour which we call the air or atmosphere (Gr. *atmos*, vapour; *sphaira*, a sphere). This aeriform fluid is drawn towards the earth and kept from flying off into space by the force of terrestrial gravity, and it thus shares in all the movements of rotation and revolution of the solid globe. Animals and plants are sub-aerial beings, that is, they live beneath this air-ocean. It is the region in which many wonderful phenomena of nature take place—clouds, fog, rain, snow, hail, thunder, lightning, winds, and storms.

199. **Composition of the Atmosphere.**—In early times air was considered as one of the elements out of which the world had originated. Air, however, is not an element, nor is it a compound. It is a *mixture* of gases, that is, the gases composing it are not chemically united, but merely in a state of admixture. *Dry air* consists of the three gases—nitrogen, oxygen, and carbonic acid—but these are mixed together in very unequal proportions. The exact proportions of these gases in 100 volumes of dry air are as follows:—

Nitrogen	79·00
Oxygen	20·96
Carbonic acid	·04
	100·00

From this table we learn that the two chief gases in air are nitrogen and oxygen, and that there is nearly four times as much nitrogen as oxygen. We have already learnt something about the gas oxygen—how it is prepared, and how it supports combustion. By removing the oxygen from a closed vessel of air we shall have nearly pure nitrogen left. To do this we take a small porcelain capsule (*c*, fig. 83) which will float on water, and put into it a small piece of phosphorus. Set the phosphorus on fire by touching it with a hot wire, and immediately invert over the capsule a bell-jar full of air, keeping the jar well under water. The phosphorus in burning takes up the oxygen from the air in the jar, forming dense white fumes of a binary compound called phosphoric pentoxide (P_2O_5). When all the oxygen has

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[1] See Note in Appendix.

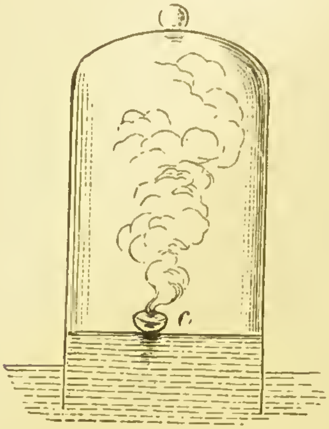

FIG. 83.—Preparation of Nitrogen from Air.

been used up the phosphorus goes out. The oxide of phosphorus falls down and dissolves in the water to form phosphoric acid (H_3PO_4); the water rises in the jar to take the place of the oxygen used up, and the jar remains about four-fifths full of a gas which is quite colourless after all the white fumes have disappeared. This gas is the nitrogen of the air. Nitrogen is a very inert gas. It will neither burn nor support combustion, and seems to serve mainly for the purpose of diluting the oxygen of the atmosphere. This experiment shows us that, roughly speaking, ordinary air consists of four-fifths nitrogen and one-fifth oxygen. More accurate experiments show that in 100 volumes of ordinary air the proportions are those given in the previous table. But, besides the nitrogen and oxygen, the air always contains a small quantity of carbon dioxide (CO_2), or carbonic acid, as it is also called, the presence of which can be shown by leaving a saucer containing lime-water exposed to the air for some time. A thin crust of calcium carbonate will then be formed on the surface of the lime-water, this formation of calcium carbonate with lime-water being the chemical test for carbonic acid. The amount of carbonic acid is only ·04 in 100 volumes, or 4 volumes in every 10,000 volumes of air. But this amount varies slightly, being a little more in large towns than in the country. We have already learnt that when coal and wood are burnt, the carbon in these substances unites with the oxygen to form carbonic acid. A still larger quantity of this gas is supplied to the air by living animals. In breathing air is taken into the lungs and thence into the blood, and in all our tissues a kind of slow combustion goes on. The oxygen of the air unites with the carbon in the blood, and carbon dioxide is then expired. Decaying plants and animals also when freely exposed to the air give off this gas, and it is one of the gases given off from volcanoes. Seeing then that carbonic acid is being supplied to the atmosphere from all these sources, it may be asked how it is that the proportion of it in the atmosphere does not increase. The explanation is that the *green* parts of *living* plants in presence of the sunlight have the power of taking the carbon from the carbonic acid in order to build up their wood and other tissues; plants decompose the carbonic acid, retaining the carbon and setting free the oxygen. The dry air of the atmosphere is always in a gaseous state, and the gases composing it are thus constant in quantity from year to year; and, though the constituent gases have different specific gravities, there is no tendency to separation among them, as gases diffuse uniformly through the space in which their particles are free to move.

Slight quantities of a gas called ammonia are present in the air, and of an active form of oxygen called *ozone*, as well as minute particles of solid matter which appear as dancing motes in a sunbeam lighting up a shady place. But besides the above gases there is always a quantity of water vapour in the air, and this quantity does not remain constant. We know that when a vessel containing water is heated till it boils the water is quickly evaporated and passes into the air in an invisible state. But a slow evaporation is going on continually from the surface of every exposed piece of water—from river, lake, sea, and very slowly even from ice and snow. In ebullition or boiling the bubbles of vapour are generated throughout the mass of the liquid, rising to the surface to escape, but in the slower process of evaporation the vapour is derived from the surface only. In whatever way, however, the water vapour is formed, the air shows no visible change on account of the aqueous vapour added to it, for true steam is invisible. The amount of water vapour present in air varies considerably from day to day, but no matter how warm and dry the day is, there is always some present. This may be proved in the following ways. Bring into a warm room a tumbler full of ice-cold water. The outer surface, though perfectly dry, soon becomes bedimmed with moisture. The reason is that the air near the cold glass becomes chilled, and as cold air cannot retain as much vapour as warm air, some of the vapour is condensed and deposited on the sides of the glass like dew. Another mode of proving that air always contains invisible water vapour is to place some strong sulphuric acid in a vessel and leave it for a time. This substance has the power of absorbing water, and after a day or two we shall be able to see that the quantity of liquid in the vessel has increased owing to the water vapour absorbed into the sulphuric acid from the air.

200. **Hygrometers and the Estimation of Water Vapour.**—The proportion of moisture or water vapour in the atmosphere is constantly varying in different districts, and sometimes from day to day and hour to hour in the same districts. It is seldom completely saturated, nor is it ever completely dry. The proportion by volume of water vapour in the air of our climate is on the average nearly 1 per cent. The amount of water vapour that the air will contain before it is completely saturated varies with the temperature, and the warmer the air is the more water vapour will it hold.[1] If we say that the air is *three-fifths* saturated we mean that it contains only three-fifths of the water vapour that it would hold at that temperature were saturation complete. An *hygrometer* (Gr. *hugros*, moist; *metron*, a measure) is an instrument for measuring the degree of moisture in the atmosphere. One of the most convenient of these instruments is Mason's Dry and Wet Bulb Thermometers. Two similar thermometers are placed on a stand side by side, one of them having its bulb covered with muslin,

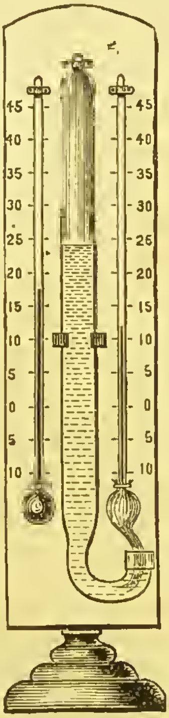

Fig. 84.
Wet-bulb Hygrometer.

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[1] In our climate the air is saturated with six grains of water in a cubic foot; the air of the Indian Ocean will hold twice as much.

which is kept constantly moist by threads connected with a vessel of water. The threads draw up the water by capillary attraction, and thus the muslin never becomes dry. This moistened muslin is constantly losing its water by evaporation, and the dryer the air the greater is the rate of evaporation. But as a liquid evaporates heat is absorbed, and this reduces the temperature of the wet bulb. The more rapid the evaporation the greater will be the difference of temperature shown by the two thermometers. Unless the air is saturated with moisture, the wet bulb always indicates alower temperature than the dry bulb. From this difference by means of tables we can calculate the degree of humidity of the air, the quantity of vapour in a certain volume of air, and the *dew-point* (see fig. 84). In the figure the thermometers are Centigrade thermometers, and the wet bulb indicates a temperature of 12° C. (= 53·6 F.), while the dry bulb indicates 17° C. (= 62·6 F.).

201. **Height of Atmosphere.**—Since the air like all other gases is very elastic and compressible, that portion of it near the level of the sea will be denser than the air near the tops of mountains, being pressed down by the mass above. The higher we go the rarer the atmosphere becomes, till at a height of about seven miles it becomes so thin or attenuated that breathing is impossible, and at a distance of forty-five miles it has been estimated to be so extremely light and rare as to be inappreciable. This limit of forty-five miles has been given on account of certain phenomena connected with twilight.

Yet we have proof that it extends even beyond this, for meteors or shooting stars have been found to be visible at a height of 200 to 300 miles, and this could only be because they had become ignited owing to the friction caused by their rapid passage through the air. These meteors are comparatively small masses of matter which, passing into our atmosphere, either become heated so intensely as to disappear in a train of blazing gas, or fall on to the earth as aërolites or meteorites. Specimens have been picked up, and on examination they are found to consist of the same elements as exist on our earth, native iron being nearly always the chief ingredient.

202. **Pressure of the Atmosphere.**—The atmosphere being acted upon by the force of gravity exerts a certain downward pressure, and being, moreover, a fluid, transmits this pressure in all directions. All fluids (Lat. *fluo*, I flow), both liquids and gases, possess this property of transmitting pressure in all directions, while a solid presses downwards only. The water in a vessel not only presses against the bottom, but also against the sides; the air in a room not only presses on the floor, but also on the side walls and the ceiling. This upward pressure of the atmosphere may be shown by a simple experiment. Take a glass tumbler with a smooth edge, fill it with water, and carefully close the mouth with a sheet of writing-paper. Keeping the paper in its place with the hand, turn the glass mouth downwards, and then remove the hand. The paper remains in its position and

the water does not fall out, as it is supported in its place by the upward pressure of the atmosphere. A man of ordinary size bears a pressure of about fourteen tons, but we are not conscious of this atmospheric pressure on our bodies, as the pressures in various directions, downwards as well as upwards, on the left as well as on the right, &c., neutralise each other, and the whole of these pressures on the outer surface is counterbalanced by the pressures from within. The gases and liquids in the tissues of our bodies are thus acting in opposition to the external pressure of the atmosphere, and the balance is so nicely adjusted that any considerable increase or diminution in either the external or internal pressures leads to serious mischief. By ascending in a balloon to a considerable height, where the air is much rarer and the pressure much less than at the sea level, bleeding from the nose and other unpleasant symptoms often arise. The average amount of the pressure of the atmosphere at the sea level is nearly fifteen pounds (14·73) on a square inch. The pressure varies a little at certain times and in certain places, and it is important that we should be able to estimate the pressure at any given time and at any given place with accuracy The instrument used for measuring the pressure or weight of the atmosphere is called a *barometer* (Greek *baros*, weight ; and *metron*, a measure), and we will now proceed to describe the construction and use of this instrument.

203. **Construction of Barometer.** Take a glass tube about thirty-three inches long, closed at one end and open at the other, fill this tube quite full with mercury, and closing the open end with the thumb, invert it in a cup or cistern of mercury so that the open end dips beneath the surface. You will then see the mercury in the tube fall for a short distance, but a column, the top of which is about thirty inches in perpendicular height from the surface of the mercury in the cistern, remains in the tube. An Italian philosopher called Torricelli was the first to make and reason upon this experiment in 1643. He argued quite correctly that the column of mercury was supported in the tube by the external pressure of the atmosphere on the surface of the mercury in the basin, this pressure being transmitted through the mercury in the basin to the under surface of the mercury in the tube. But the tube being closed above, there is no pressure at the top, and the space above the mercury in the tube is quite empty, and is known as the *Torricellian vacuum*. Were a hole made through the closed end at the top of the tube, the upward pressure of the air through the liquid in the

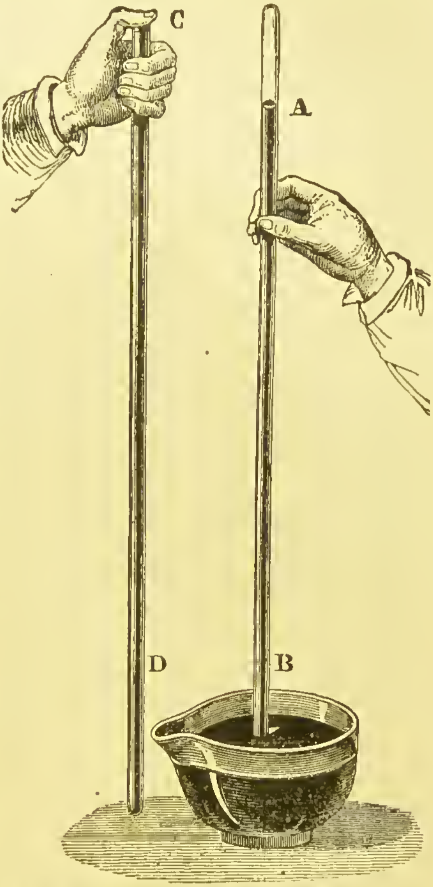

FIG. 85.—Filling the Barometer Tube.

basin would be just counterbalanced by the downward pressure of the air at the top; the mercury would then fall by its own weight. Since the pressure of the atmosphere just balances a column of mercury thirty inches high, it follows that if we can find the weight of this mercury column we shall learn the weight of a column of air standing on a base of the same size and reaching to the top of the atmosphere. It is found that a column of mercury in a tube having a sectional area of one square inch and a height of thirty inches weighs about fifteen pounds. Hence, as before stated, the weight or pressure of the atmosphere is nearly fifteen pounds on every square inch. A *barometer*, then, in its simplest form consists of a tube dipped into a cistern of mercury, and containing a column of that liquid supported by the atmospheric pressure which it serves to measure. The height of the column is the perpendicular difference in level between the surface of the liquid in the tube and in the cistern. The tube and cistern are usually attached to a wooden frame, and a graduated scale divided into inches and fractional parts is placed parallel with the tube. As the atmospheric pressure varies, the height of the mercurial column varies; mercury is forced into the tube as the pressure increases; as the pressure diminishes mercury passes from the tube into the cistern. In Fortin's barometer the base of the cistern is made of leather, and can be raised or lowered by means of a screw. In this way the surface of the mercury in the cistern can be kept at a constant level, so that the graduation on the scale always indicates the true height. Other forms of barometers are in use, but a good cistern barometer is the best. A barometer called the Aneroid Barometer (Gr. *a*, not; *neros*, moist) has lately come into use, and is found to be very convenient for some purposes, as it requires neither mercury nor any other liquid. It consists of a cylindrical metal box exhausted of air, and formed of corrugated elastic metal. In the interior is a system of wheels and levers connected with a pointer which moves over a graduated scale. As the pressure of the atmosphere increases, the metallic chamber is slightly contracted, and this movement is carried by the internal mechanism to the pointer. A decrease of pressure allows the box to expand slightly, and the pointer is moved in the opposite direction. The positions of the figures on the scale are obtained in the first instance by comparing the instrument with a good mercurial barometer.

204. **Advantages of Mercury for Barometers.**—Mercury is generally used for barometers in preference to other liquids because it is the heaviest of all liquids, and the height of the column is therefore small and more easily observed. It is also used because it does not wet the glass, and because it does not evaporate from the cistern. If water were used, the *water barometer* would be nearly thirty-four feet high when the mercurial column stood at 30 inches; for the specific gravity of mercury is 13·5, that of water being 1; and 30 inches multiplied by 13·5 is nearly 34 feet. *Glycerine*, however, is sometimes used. The length of its column is rather more than ten times that of mercury, and hence small alterations of atmospheric pressure cause larger and more distinct changes in the level of the tube than in the mercurial barometer.

205. **Density and Pressure of the Atmosphere at Different Heights.**—The pressure of the air decreases gradually as we ascend above the sea level. That this is so will be plain when we consider that as we ascend the superincumbent mass diminishes; the higher we go the thinner becomes the layer of air above us. But, in consequence of the law that the volume of a gas is inversely proportional to the pressure to which it is subject, the

density of the air diminishes as well as the pressure. If we imagine the atmosphere divided into layers, the more compact layers will be at the bottom, just as in a stack of hay. On the summit of Mont Blanc, 15,000 feet high, the barometer only indicates about 15 inches pressure, and hence the air there is only one-half as dense as it is at the level of the sea, its particles being at twice the distance. In other words, a given weight of air will occupy twice the volume that the same weight occupies at the sea level. Hence at great heights animal life cannot be supported (see par. 201). As the barometer falls the higher we ascend, it is plain that if we knew the law by which this fall takes place, we could ascertain the height of a mountain by means of the instrument. The law is rather complicated, but for small elevations a fall of 1 inch in the barometer indicates a height of 900 ft. A better but still only an approximate rule is, 'Observe the heights of the barometer at the bottom and at the top of the mountain; divide the difference of the heights by the sum, and multiply the result by 52,428: this will be the height of the mountain in feet.' The use of the barometer to measure heights is often of great advantage to travellers.[1]

The diagram represents a natural section of the atmosphere. On the left is shown the height in miles above the sea level, while on the right is shown the corresponding heights of the barometer in inches. A indicates the highest peak in the Himalaya Mountains (29,000 feet); B, the height (23,019 feet) attained by Gay Lussac in a balloon in 1804 (Mr. Glaisher and Mr. Coxwell reached a height of 37,000 feet, or 7·137 miles, in 1862); C, Dolcoath mine, in Cornwall, 1,560 feet (the deepest mine is now 2,800 feet); D, a depth of nearly 9 miles. But no such depth has really been found, the deepest reliable sounding being up to the present only 28,000 feet, or nearly 5½ miles, off the coast of Japan.

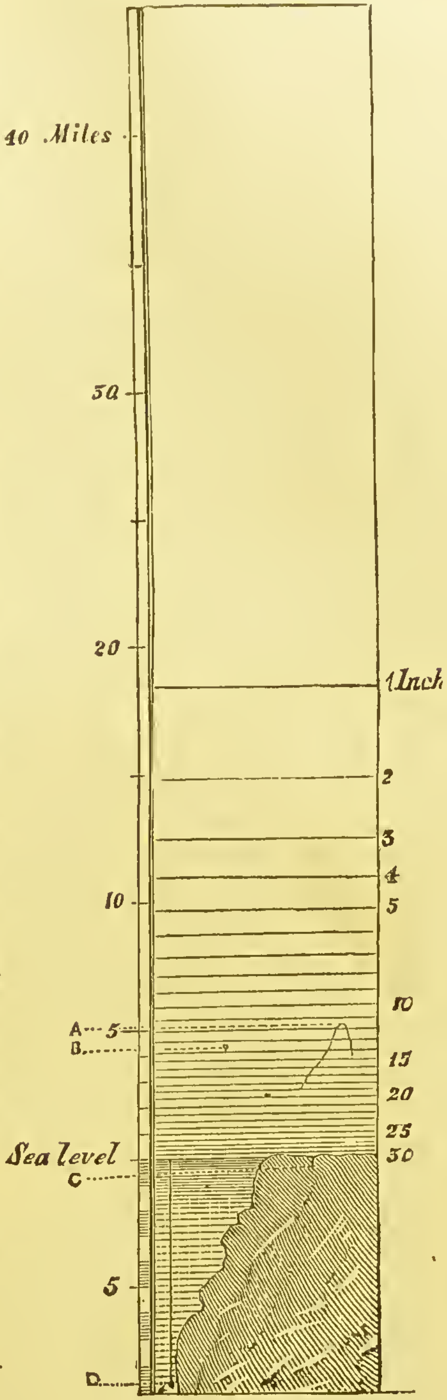

FIG. 86.—Section of Atmosphere.

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[1] Mr. Whymper's barometer gave a reading of 14·1 inches on the summit of Chimborazo, 20,500 feet high.

206. **Variations of Barometric Pressure.**—Not only does the pressure of the atmosphere vary at different heights, but it varies at the same level at different places on the earth, and also at the same place at different times. The two chief causes of this variation are—(1) the varying temperature of the air; (2) the varying quantity of aqueous vapour in the air. It is a general rule that the barometer usually falls when the thermometer rises, and the barometer usually rises when the thermometer falls. The heat that causes the thermometer to rise expands the air, which consequently overflows into the neighbouring regions; and the pressure of the atmosphere being thus diminished, the barometer falls. On the other hand, when the thermometer falls, owing to a diminution of temperature, the air contracts, and this produces an influx from the neighbouring regions, and consequently an increase of pressure and a rise of the barometer. This influx of air is generally accompanied by descending currents, while an expansion of the air causes ascending currents. Thus where there are descending currents in the atmosphere the pressure will increase, and where there are ascending currents in the atmosphere the pressure will decrease. Remembering that, generally speaking, the heating power of the sun's rays is greatest at the equator and decreases towards the poles, we may expect that the heated air near the equator expands, rises, and overflows, and that therefore the pressure will be less at the equator than in higher latitudes. But, owing to the spherical form of the earth, the air flowing towards the poles moves into a region becoming narrower and narrower, and is at last brought down to the surface of the earth at about the 30th parallel of latitude. Here we find a region of high pressure on both sides of the equator. The air is chiefly heated, as we shall presently show, by contact with the surface of the globe; and as the heating effects of the sun's rays on land and water are very different, variations of temperature, and therefore of pressure, in a district depend to some extent on whether the surface is land or water. The other chief cause of differences in barometric pressure is due to the varying quantity of water vapour in different places, and even in the same places from day to day.[1] Water vapour is much lighter than air, and the addition of a considerable quantity of vapour lessens the pressure of the atmosphere, and causes the barometer to fall, the mixture of air and vapour being lighter than dry air. In regions like the Antarctic Circle, where there is a large quantity of vapour, the barometer stands low; but in almost every region the quantity is nearly always changing, sometimes increasing from great evaporation, sometimes diminishing from being condensed into rain, hail, or snow. A fuller account of the regions of high and low pressure is contained in 'Advanced Physiography.'

207. Mr. R. H. Scott gives the following statements from Professor Mohn's 'Treatise on Meteorology:'—

The barometer stands high—

(1) When the air is very cold, for then the lower strata are denser and more contracted than when it is warm.

(2) When the air is dry, for then it is denser than when it is moist.

(3) When in any way an upper current sets in towards a given area, for this compresses the strata underneath.

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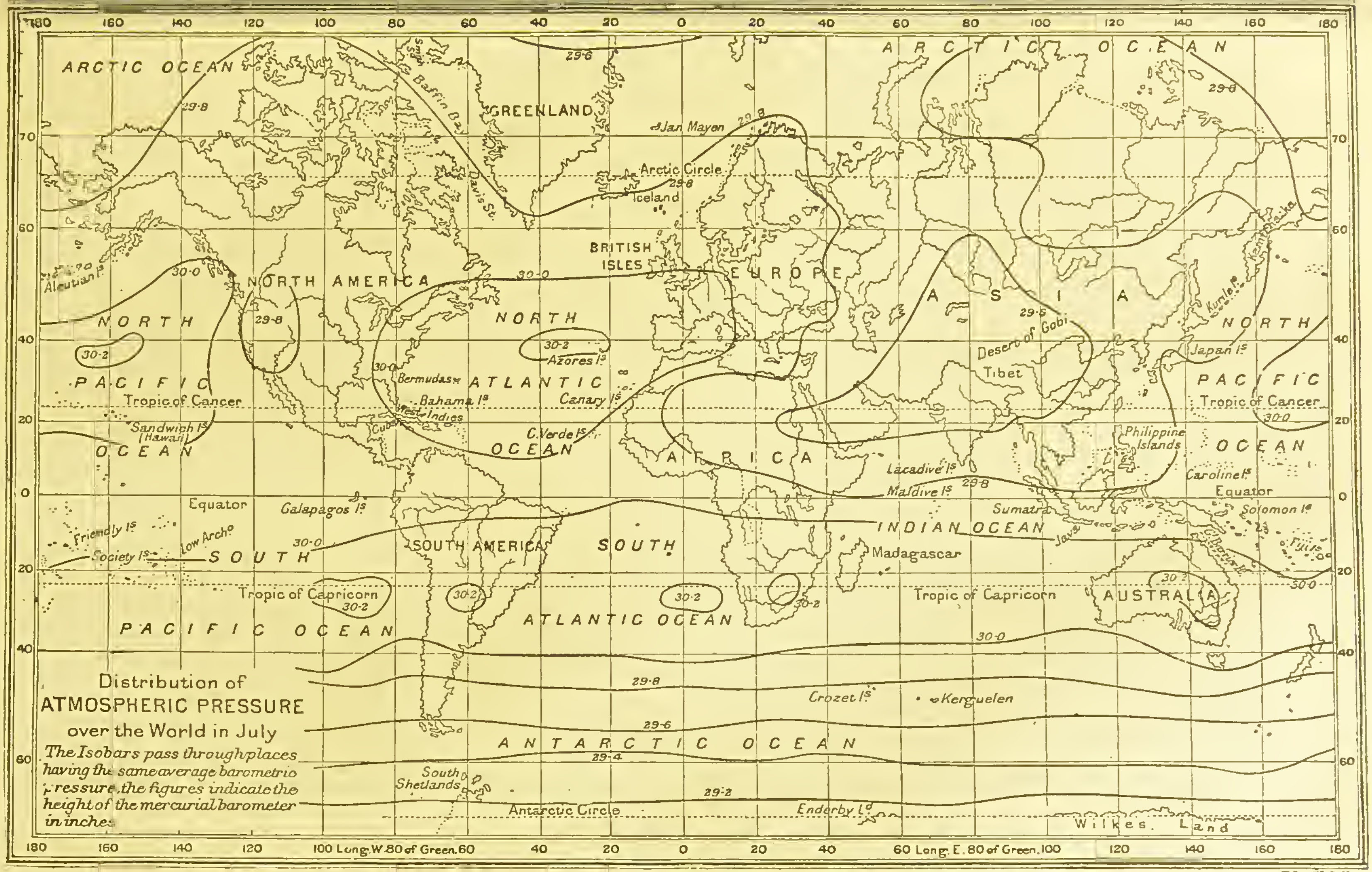
[1] Between the tropics the diurnal variation amounts to one-tenth of an inch, there being two highest and lowest points at regular periods of the day. In the temperate zones the diurnal variation is less, and not easily observed owing to its occurrence in conjunction with accidental variations.



Edwd. Welles

Map V.

Conversely, the barometer stands low—

(1) When the lower strata are heated, causing the surfaces of equal pressure to rise and the upper layers to slide off, as already described, for by this means the mass of air pressing on each unit of area below is reduced.

(2) When the air is damp, for as the density of aqueous vapour at the temperature of 60° and pressure of 30 in. = 0·622, air being = 1, the mixture is lighter the more vapour it contains, and consequently damp air does not press so heavily as dry on the unit of area below.

(3) When the air from any cause has an upward movement, for this of course acts in the same manner as (1).

208. **Isobars** (Gr. *isos*, equal ; *baros*, weight).—Isobars are lines drawn through places having an equal barometric pressure during a certain period. They may be drawn for each month or season, or for the whole year. These isobars are usually drawn at differences of $\frac{1}{10}$ of an inch. In the *Times* newspaper there is each day a chart of North-western Europe, on which the isobars, the temperature, and the direction and force of the wind are shown for the previous day. On the accompanying map are drawn isobars through those places having the same average pressure during the month of July. If we were to compare it with one for January we should easily see how the pressure is affected in some districts by the season of the year (being usually less in summer than in winter), and how the land and water cause local differences of pressure.

Thus in January we find a pressure of nearly one inch more in Central Asia than we do during the great heat of July, while over the oceans generally, except in the higher northern latitudes, the pressure is more regular during the year than over the land. Taking the surface of the globe as a whole, we find that there are two belts of high pressure passing round the globe, one on each side of the equator. Between these two lies a belt of low pressure in the tropical regions, the lowest mean pressure of this belt being near the equator. Two other regions of low pressure surround the poles, the one round the north pole being divided into two centres.

209. **Relation of Barometric Variations to the State of the Weather.** In Ganot's 'Treatise on Physics,' as edited by Professor Atkinson, the following remarks are made under this head :—

'It has been observed that, in our climate, the barometer in fine weather is generally above 30 inches, and is below this point when there is rain, snow, wind, or storm ; and also that for any given number of days at which the barometer stands at 30 inches there are as many fine as rainy days. From this coincidence between the height of the barometer and the state of the weather the following indications have been marked on the barometer, counting by thirds of an inch above and below 30 inches:—

Height	State of the Weather
31	Very dry
$30\frac{2}{3}$	Settled weather
$30\frac{1}{3}$	Fine weather
30	Variable
$29\frac{2}{3}$	Rain or wind
$29\frac{1}{3}$	Much rain
29	Storm

'In using the barometer as an indicator of the state of the weather we must not forget that it really only serves to measure the weight of the atmosphere, and that it only rises or falls as the weight increases or diminishes; and although a change of weather frequently coincides with a change in the pressure, they are not necessarily connected. This coincidence arises from meteorological conditions peculiar to our climate, and does not occur everywhere. That a fall in the barometer usually precedes rain in our latitudes is caused by the position of Europe. The prevailing winds here are the south-west and north-east. The former, coming to us from the equatorial regions, are warmer and lighter. They often, therefore, blow for hours or even days in the higher regions of the atmosphere before manifesting themselves on the surface of the earth. The air is therefore lighter, and the pressure lower. Hence a fall of the barometer is a probable indication of the south-west winds which gradually extend downwards, and reaching us, after having traversed large tracts of water, are charged with moisture and bring us rain.

'The north-east wind blows simultaneously above and below, but the hindrances to the motion of the current on the earth by hills, forests, and houses cause the upward current to be somewhat in advance of the lower ones, though not so much so as the south-west wind. The air is therefore somewhat heavier even before we perceive the north-east, and a rise of the barometer affords a forecast of the occurrence of this wind, which, as it reaches us after having passed over the immense dry tracts of land in Central and Northern Europe, is mostly dry and fine. When the barometer rises or sinks slowly, that is, for two or three days, towards fine weather or towards rain, it has been found from a great number of observations that the indications are then extremely probable. Sudden variations in either direction indicate bad weather or wind.'

210. **Corrections of the Barometer.**—In making accurate observations corrections have to be applied to the barometer—(1) for the height of the observing station above the sea level; (2) for temperature. In order to compare barometric indications taken at different places, it is necessary to reduce them to a common height, and the sea level is taken as the standard height. The higher the place is above the sea level the lower will be the reading of the barometer. The rule applicable to the estimation of heights already referred to is made use of for this purpose. The correction for temperature is necessary because the mercury expands and contracts for differences of temperature, and hence different atmospheric pressures might indicate the same height if the temperature varied. Hence barometers usually have a thermometer attached in order to show the

temperature at the time of observation. The rule often given is, 'Deduct the ten-thousandth part of the observed height for each degree of Fahrenheit above 32°.' All observations are thus reduced to a common temperature.

211. **Temperature of the Air.**—*How the Air is heated.*—We have already explained in par. 52 how the temperature of the air is ascertained by means of the thermometer, and we have now to explain how the air is heated and in what way its temperature varies. The earth receives nearly the whole of its yearly supply of heat from the rays of the sun, the supply that comes from the interior being inappreciable at the surface. Dr. Haughton says, 'The heat received from the interior of the earth at present is sufficient to melt a layer of ice one quarter of an inch in thickness all over the surface of the globe; while that received from the sun would melt a layer forty-six feet in thickness, being thus 2,208 times greater than the heat derived from the interior.' If there were not water vapour in the atmosphere the rays of heat from the sun would pass through it without suffering loss, and a great portion of what reached the earth would then be absorbed by the rocks and soil covering its surface. But, as the air always contains more or less aqueous vapour, there is a certain quantity of the sun's rays absorbed by the atmosphere, and the greater the distance of air through which the sun's rays pass, and the richer the strata of air are in this water vapour, the greater is the number of the sun's rays that are absorbed. As the rays of the sun pass through a much larger thickness of air in the morning and at night than during the middle of the day, the amount of heat that reaches the earth is made less at these times than at noon. Hence the greater warmth of the sun's rays at midday. It has been estimated that in this way a vertical beam loses about 20 per cent. of its heating power, and that in the morning or evening the loss is nearly 95 per cent. The average loss in our latitudes is nearly 50 per cent.

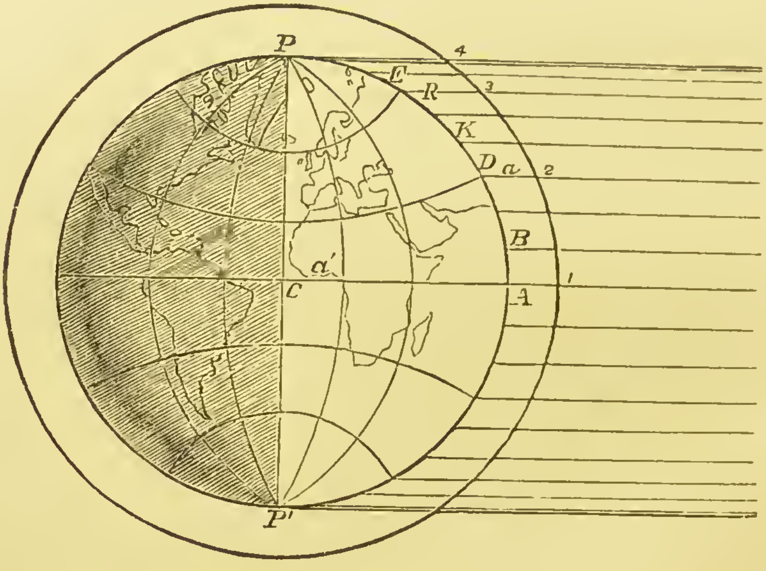


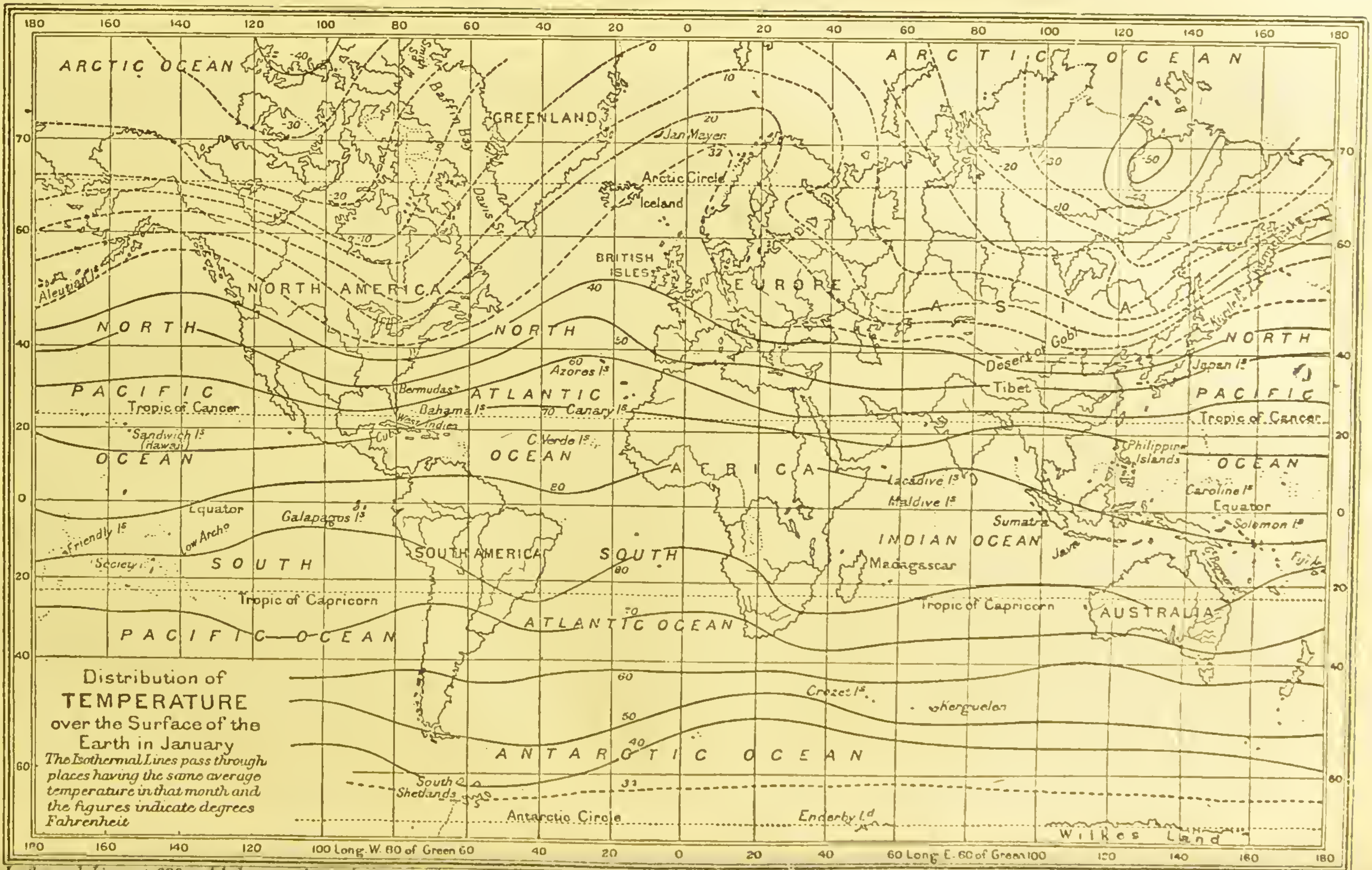
FIG. 87.

There is also another reason why it is warmer at noon than in the morning or evening. If we imagine a cylindrical beam of rays of a certain size striking the earth, we shall easily see that when these rays come perpendicularly they fall on a much less surface than when they fall obliquely. The heating power of such a beam is concentrated on a smaller area the more nearly vertical the beam is. For similar reasons it is warmer near the equator than near the poles. Fig. 87 represents the earth, the axis being in the position with regard to the sun that it has on March 21 and September 23. The sun is supposed to be at an immense distance to the right, and his rays are represented as coming in parallel lines towards the earth. The half meridian circle is divided into 18 equal parts of 10° each, 9 parts being included between A and P. It is easy to see that the rays strike the earth more obliquely as they approach the pole. If we suppose each pair of lines to represent a bundle of rays, we see that each of these bundles becomes narrower towards the poles, and that, therefore, each of the equal strips of 10° gets a smaller quantity of light and heat as we leave the equator. The outer circle represents the atmosphere, and here also we see how the distance of the ray through the atmosphere increases as we approach the poles. For 1A is shorter than 2D, still shorter than 3E, and still shorter again than 4P.

Of those rays that reach the surface we find that some are reflected or thrown back, but that they are mostly absorbed by the ground and then slowly radiated back. Both the rays that are reflected and those that are absorbed heat the air; for these rays are rays of dark heat, unlike the sun's luminous rays, and can be absorbed in great part by the overlying atmosphere. As was explained in par. 66, the presence of water-vapour in the atmosphere greatly checks radiation from the earth, the moisture acting as a screen or covering spread over the earth, allowing the luminous rays from an intensely heated source like the sun to pass through rather freely, but restraining the non-luminous rays from a source of lower temperature like the heated earth. Gradually, however, the warmth passes from the lower into the upper atmospheric strata, and is then lost by radiation into the intensely cold regions of space, the loss being about equal to what is received.

212. *Mean Temperatures.*—The average temperature of the day may be found by taking the temperature every hour and dividing by twenty-four, though it is generally sufficient to take only two observations, one at 9 A.M. and one at 9 P.M., and divide by two. The average temperature for any month may be obtained by dividing the sum of the daily averages by the number of days in the month, and the yearly average by dividing the sum of the monthly average by twelve. The hottest part of a clear day, as shown by the shade thermometer, is usually about two o'clock in the afternoon, and the coldest part is in the early morning about four o'clock. The hottest period of the year in the Northern Hemisphere is towards the end of July, for during the summer the heat has been accumulating owing to the amount of heat received from the sun being then greater than that lost by radiation.

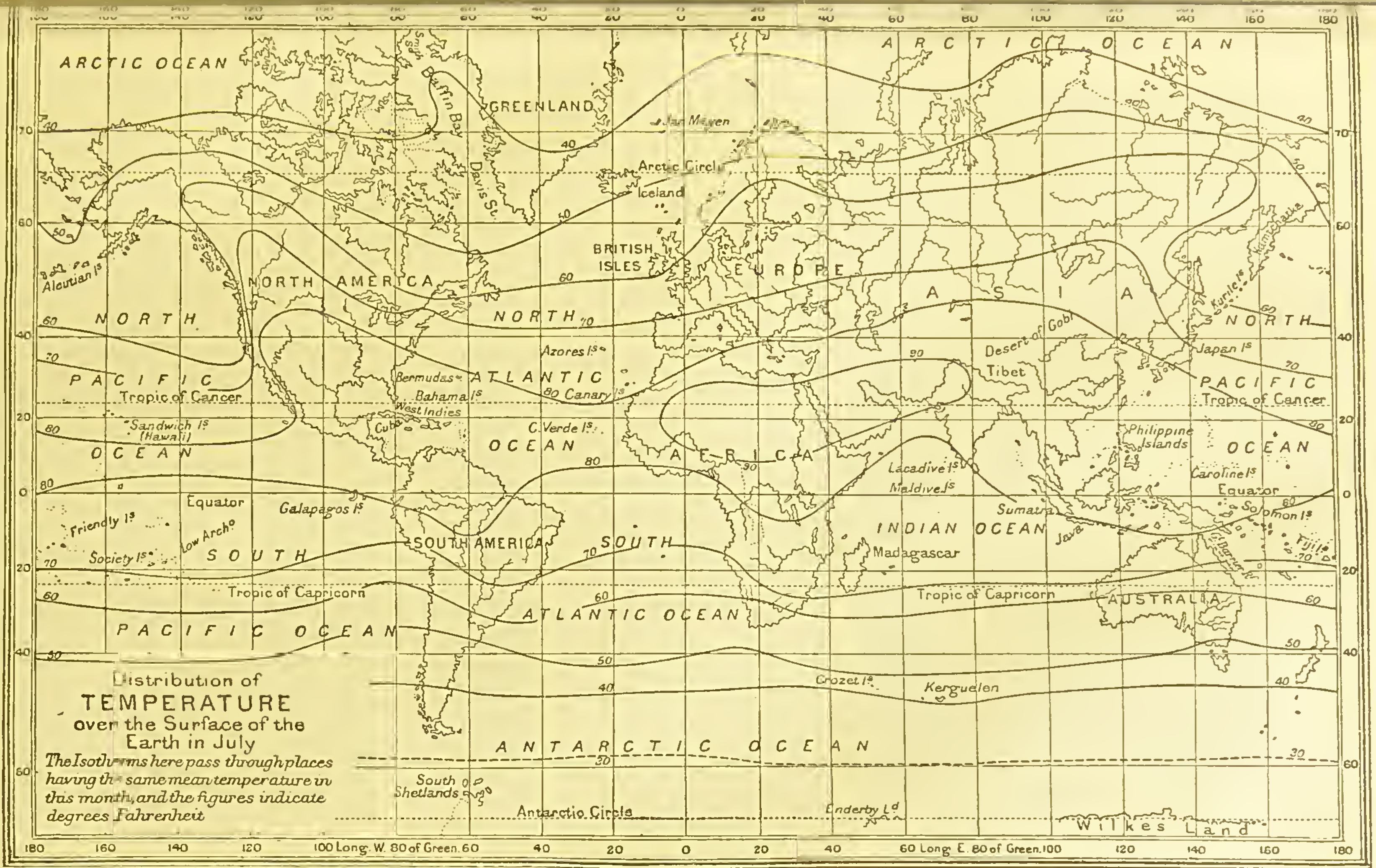
213. *The Temperature depends on Latitude.*—From what has just been said, and from the fact that the solar rays are nearly vertical at and near the equator, we see that the equatorial belt of the globe will have the highest temperature, and that, generally speaking, the further we go from the equator the colder will it become, the angle at which the solar rays strike the earth diminishing as we pass towards the poles (fig. 87). If, then, there were no other cause, we should have a regular diminution of temperature from the equator to the poles, and every place in the same latitude would have the same temperature. But we know that this is not the case, even at the same height above the sea level. When we examine



Distribution of
TEMPERATURE
over the Surface of the
Earth in January

The Isothermal Lines pass through places having the same average temperature in that month and the figures indicate degrees Fahrenheit

Isothermal Lines at 32° and below are shown by pecked lines.



Distribution of
TEMPERATURE
over the Surface of the
Earth in July

The Isotherms here pass through places having the same mean temperature in this month, and the figures indicate degrees Fahrenheit

Isothermal Lines at 32° and below are shown by pecked lines.

Edwd Weller

MAP VII.

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a chart of the world on which isotherms (Gr. *isos*, equal; *thermos*, heat) are drawn through places having the same temperature of the air during a given period, we see that these lines are very irregular and vary considerably at different seasons, especially over continental areas. On referring to the maps on which the isothermal lines are drawn for January and July it will be seen how very irregular these lines are in the Northern Hemisphere, and how comparatively regular they are in the Southern Hemisphere, where there is a great preponderance of water. These lines thus show that temperature depends more on latitude in the great oceanic areas of the globe than in the continental areas, or in the regions where the sea and land come together. As a rule, the Northern Hemisphere is seen to be warmer on the average than the Southern, except in high latitudes,[1] where the converse is true, the land also being generally warmer than the sea in low latitudes, but colder in higher latitudes. They also show that the district of greatest heat, especially in summer, is the interior of continents, the deserts of Africa and Persia having a July temperature of 90°. The temperature of the sandy *ground* in these parts is often above 160° F. There must therefore be some other causes modifying the effect of position as regards the equator. Among these are the prevailing winds, proximity to the sea, position of mountain chains, and the altitude of the land. We shall now discuss this last, leaving the others till we speak of Climate.

214. *Temperature depends on Height above the Sea Level.*—Since the first effect of the sun's heat after it has warmed the surface of the earth is to warm the parts of the atmosphere in contact with the surface, and since this warmth is but slowly passed on through the higher layers, we find that the air near the surface is warmer than the air above. But there are other reasons why the air is colder at a distance from the surface.

It is quite true that on high mountains the intensity of the *solar* radiation is greater than in the valleys, and that therefore the traveller who is there exposed to the direct rays of the sun may have his skin blistered by the great heat, though another in the shade may feel great cold. But this heat is not communicated to the air; for the air becomes rarer the higher we ascend, and also holds less moisture. Consequently it is but little heated either by the luminous rays of the sun or by the rays radiated from the rocks. There is thus no protective water-vapour in the atmosphere to check the rapid radiation into space when the sun is not shining, and there is thus no store of heat retained in the soil as at low levels.

Another property of air also tends to diminish the temperature at great heights. When a mass of air expands, heat is used up to perform this work and the air becomes cooler. Warm winds, therefore, from a valley, when forced up the sides of a mountain, expand in consequence of the diminished pressure at the greater height, *and in expansion become greatly cooled.* This diminution of temperature in ascending currents is greater with a dry wind than with a moist wind, as, in the latter case, while heat is lost through expansion, some is gained by the vapour that condenses giving up its *latent heat*, so that this latent heat lessens the rate of cooling. The diminution, too, is greater during the day than during the night; greater in summer than in winter. In severe frosts, indeed, the temperature may rise with height, instead of falling, all the cold dense air remaining in the lowlands beneath. We thus see that the lower temperature of the air at greater heights is due to two chief causes, the diminishing thinness and dryness of the protective coating of the atmosphere and the disappearance of heat consequent on the expansion of the ascending air-currents.

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[1] High latitudes are latitudes near the poles; and low latitudes, latitudes near the equator.

This *vertical distribution of temperature*, as it is called, to distinguish it from the *horizontal distribution*, shown by the isothermal lines, which show the temperatures at the surface, may be reduced to a general rule. The rate of diminution may be taken on the average at a fall of 1° F. for every 300 feet of ascent.

215. **Land and Sea Breezes.**—Winds are movements of air in currents from one part of the atmosphere to another. They are caused by variations in the condition of the air in respect to heat and moisture, and, as these variations produce differences in atmospheric pressure, movements are set up, there being always an inflowing towards regions of low pressure. We shall here confine ourselves to the *local* movements called land and sea breezes. These occur chiefly on the coasts of tropical countries, though they are also found during warm weather in our own islands, when not overpowered by a strong general wind. They are more frequent about islands and small peninsulas than in other situations. They blow alternately from the sea on to the adjacent land (sea breeze), and from off the shore to the sea (land breeze). A little before noon the sea breeze begins in the offing and gradually extends to the coast, lessening and dying away towards the evening. A short period of calm follows, and then some time before midnight the land breeze comes from the shore and blows towards the sea until six or seven o'clock A.M. These winds are due to the different manner in which the sun's heat affects the land and water, and also to the different radiating power of the two surfaces. The surface of the sea is not raised to so high a temperature during the day as the surface of the land, partly because the solar heat penetrates further into the water than into the land, but chiefly owing to the greater specific heat of water (see par. 63), in consequence of which it requires nearly five times as much heat to raise its temperature one degree as the rocks forming the land surface require.

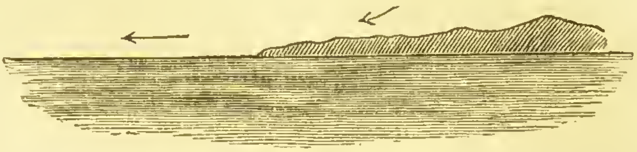

FIG. 88.—Land Breeze by Night.

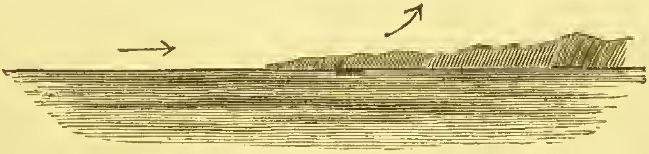

FIG. 89.—Sea Breeze by Day.

On the other hand, the sea does not lose so much heat at night by radiation as the land does, and accordingly it preserves a comparatively equable temperature throughout the day. The temperature of the land surface thus undergoes far greater changes of temperature than the sea surface, and this is of course also true of the air lying above both. Calm prevails as long as the temperatures over land and sea are the same; but as the solar rays become hotter towards noon, the more strongly heated land communicates its heat to the overlying air, and this causes it to expand and become rarer. A diminution of pressure on the land surface is the result. In the *higher* air regions above the land there is an overflow of the air *outwards* from the heated part towards the cooler air at some distance over the sea. Hence the pressure over the sea rises, and very soon afterwards an equalising air current arises in the *lower* parts of the atmosphere and flows *inwards* towards the heated land, and is therefore called a *sea breeze.* The strength of the sea breeze is not always the same. It increases until the difference of temperature between the land and sea is at its maximum, and then gradually diminishes until about equal temperatures are found.

As soon as the sun's rays cease the land cools down much more quickly than the sea, and hence the temperature of the air above the land falls. The air masses over the land thus contract and the pressure increases. There is therefore *above* a current of air from the sea towards the land, which assists in increasing the pressure over the land and diminishes it over the sea. In accordance, then, with the general law that currents blow from regions of high pressure to those of lower pressure, an equalising stream sets in from the land towards the sea and so develops a *land breeze.* The time during which a land breeze blows is usually from an hour or two before midnight until six or eight o'clock in the morning.

Diurnal winds, similar to land and sea breezes, termed *mountain and valley winds*, prevail in some mountainous districts. The slopes of the mountain exposed to the sun's rays become more heated during the day than the land surface of the valley, and the air resting on the slope becoming hotter than that in the valley flows off above. A difference of pressure is thus set up, and a surface wind blows up the valley by day. At night the slope of the mountain quickly cools, and the air resting upon it becomes denser than that in the valley. A breeze from the mountain then passes down the valley in the night.

215*a*. **Trade Winds, Monsoons and Cyclones.**—Near the earth's equator, under the vertical rays of the sun, there is enormous evaporation and great heating of the surface with consequent heating of the air resting upon it. Hence arises an equatorial belt of low pressure (referred to in par. 206), for the hot moist air expands, and ascending flows off above towards the poles, thus reducing the atmospheric pressure near the equator. This equatorial belt of low pressure, a few degrees in breadth, forms a *zone of calms*, with frequent heavy rains often accompanied by violent thunderstorms. This belt of calms (Doldrums) advances towards the north in summer, as the sun is then above the equator, and towards the south in winter, as the sun is then below the equator. In fact, it follows the *thermal equator*, as the line along which the greatest heat on the earth's surface at any season is called. The expanded and rising air of the calm belt leads to the steady inflow of surface winds from regions of greater pressure in higher latitudes towards the equator. If the earth were at rest, a north wind would prevail at the north side of the calm belt and a south wind on the south side of the calm belt. But the earth's rotation deflects these winds to the right in the northern hemisphere and to the left in the southern, their directions becoming more and more easterly as they approach the equator. These regular winds, from the north-east on the northern side of the equator, and from the south-east on the southern side of the equator, constitute a regular system of currents known as the *trade winds*. Over the land the greater friction and the irregular distribution of temperature disturb their uniformity, and hence they are most marked in the open sea, where the surface temperature is more uniform.

The **trade winds**, then, are constant winds blowing in a regular trade or course over the oceans towards the equatorial region of low pressure, those in the northern hemisphere, starting about 30° N. lat. and being deflected towards the right by the earth's rotation, constituting the *north-east trades*; and those in the southern hemisphere, starting about 30° S. lat. and being deflected towards the left, constituting the *south-east trades*. Both die out as they approach the belt of calms.

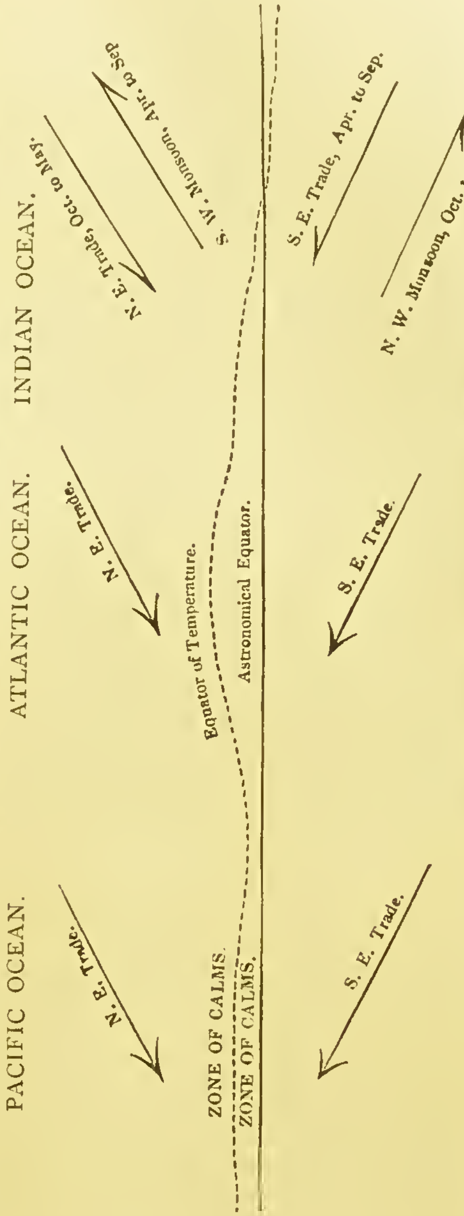

FIG. 90.—Diagram of Winds within the Tropics.

Beyond the borders of the trade winds in both hemispheres the prevailing winds are from the south-west or west, but these westerly winds are not so regular as the trade winds. These westerly winds arise in great part from the upper currents that flow from the equator, and descend to the surface about the thirtieth parallel of latitude, where they produce the *calms of*

Cancer in the northern hemisphere, and the *calms of Capricorn* in the southern. Continuing northward or southward, and being deflected to the right or left according to the hemisphere (north or south) by the earth's rotation, they form the westerly winds or *anti-trades* of temperate latitudes (see Map X.).

Monsoons are *periodic* winds that blow over the Indian Ocean and adjacent lands — a *north-east monsoon* during the winter months from October to March, and a *south-west monsoon* during the summer months from April to September. During the cooler half of the year, the north-east monsoon is in fact the regular trade wind of the northern hemisphere. The change to a south-west monsoon in summer is the result of the sun's heat upon the continent of Asia. In summer the heat upon the southern part of Asia is greater and the air less dense than that of the Indian Ocean, and consequently air passes from the region of higher pressure over the ocean to the region of lower in Asia, and, being deflected by the earth's rotation to the right, become the *south-west monsoon*. The change of monsoons is usually accompanied by violent storms. It is this south-west wind laden with vapour that produces the great summer rainfall on the high range of mountains in the north of India (par. 225).

The variable winds of the north temperate zone either blow, as a rule, inwards towards a centre of low pressure, or outwards on all sides from a centre of high pressure. A wind-system in which the wind blows spirally around and in towards a centre of low pressure is called a **cyclone** (Gr. *kuklos*, a circle), as the isobars outside the centre have a more or less circular shape. A wind-system with light winds flowing outwards from a centre of high pressure is known as an **anti-cyclone**. 'The direction in which winds blow spirally inwards in a cyclone is (in the northern hemisphere) opposite to that of the movements of the hands of a watch lying face upwards ; in an anti-cyclone the opposite. The position of an anti-cyclone is usually pretty constant for days, or even weeks together, but that of a cyclone is constantly changing, as the centre of low pressure is always shifting, generally in a more or less easterly direction.' Other revolving storms of wind and rain are known in different regions as *hurricanes*, *typhoons*, or *tornadoes*, as well as cyclones. (For a fuller account of winds, see 'Advanced Physiography.')

CHAPTER XI.

EVAPORATION AND CONDENSATION—DEW, MIST, FOG, RAIN, AND SNOW.

216. **Evaporation** is the process by which a liquid is changed into a state of vapour, and this is one of the most important effects of heat. During the process a considerable quantity of sensible heat passes into the *latent* or insensible state (par. 60), and hence evaporation has a cooling effect on the body from which the vapour rises, and the cooling is greater in proportion as the evaporation is more rapid. This heat makes its

appearance again when the vapour is condensed or re-converted into a liquid. Water evaporates at all temperatures, though most rapidly during the process of boiling or ebullition (par. 61). But even snow and ice give off vapour from their surface. A piece of ice placed in the balance-pan of the scales and carefully weighed will be found to diminish in weight slowly, though the air may be below freezing-point. Whatever, therefore, may be the temperature of the air, it is almost constantly receiving aqueous vapour from the surface of the water and moist ground. This evaporation is due to the heat of the sun, and is therefore most active in the equatorial regions of the earth, where the sun's rays are most powerful. This vapour rises in an invisible form and diffuses itself through the atmosphere. It really exists in the spaces between the air particles, though it is convenient to speak of it as contained in the air. A certain quantity of air, say a cubic foot, is only capable of receiving a certain quantity of vapour at a certain temperature and pressure. If we increase the temperature or diminish the pressure the air becomes capable of holding more vapour. At the freezing-point air is only capable of holding about one-tenth the quantity it holds at 60° F., the temperature of an ordinary summer day, while air at 80° F. has nearly twice the capacity for vapour that air at 60° F. has. When air contains all the vapour that it is capable of containing at a certain temperature it is said to be *saturated.* As soon as the air which is saturated with vapour has its temperature lowered, some of the vapour is condensed and passes into the liquid form ; or if the temperature be lowered below freezing-point, it will become solid.

217. **Condensation**, then, is the process by which a vapour or gas is converted into the liquid or solid form, and this process is brought about either by the application of cold or an increase of pressure. Distillation is the process of evaporation and subsequent condensation into falling drops, and is often employed by the chemist to free water from the impurities dissolved in it (see par. 22). It must be borne in mind that all distilled water, whether it be obtained by the rapid process of the chemist or by the slow process going on in nature, is pure water, the dissolved matter being all left behind. The condensation of the vapour of the air is nearly always the

result of a diminution in temperature, in consequence of which the capacity of the air for water vapour is lessened, and a portion of it is therefore thrown down. Thus, if air at 80° be saturated, and its temperature be then reduced to 60°, about one-half its vapour would be condensed during this reduction of temperature. The quantity of vapour in the air varies greatly with the seasons, the climate, the height above the sea, and various local causes. It is hardly ever completely saturated, nor ever entirely dry, and is constantly varying. The rate of evaporation is influenced by several circumstances. The larger the surface of a given quantity of water, the more rapidly does it evaporate, for, except the liquid be boiling, the evaporation takes place at the surface. Heat also increases the process, as it is well known that holding a towel before the fire dries it more quickly than leaving it exposed on a line. Wind also increases the rapidity of evaporation by bringing fresh layers of non-saturated air in contact with the wet surface. The hygrometric (Gr. *hugros*, moist) state of the air has also to be considered, for if the air be already nearly saturated, it takes up additional moisture very slowly; while, if it is nearly dry, it takes up the moisture quickly. There is usually more aqueous vapour in the air in summer than in winter, for then the air is warmer and is capable of holding more vapour, though it may not feel so damp. As already mentioned, this aqueous vapour is chiefly found in the lower atmospheric strata, and diminishes so rapidly that at a height of five or six miles it is scarcely appreciable. The amount of aqueous vapour, or, more exactly, the relative humidity of the atmosphere, is ascertained by means of the hygrometer, already explained. The important part played by this aqueous vapour in allowing the rays from a highly heated source like the sun to pass through it freely, and in obstructing the heat-rays from a body of much lower temperature like the sun-warmed earth, has been already referred to (par. 66).

218. **Dew.**—One of the forms in which the atmosphere restores part of its vapour to the earth is dew. Dew is moisture deposited as small drops from the atmosphere without the formation of any visible cloud. Towards sunset the heat received by the earth from the sun becomes less than the heat radiated from its surface. If the sky be clear, this heat radiated from the earth passes into space and the ground becomes cool, and bodies near its surface are thus chilled. The layer of air in contact with these bodies also becomes chilled, and at last descends to a degree of temperature at

which it is saturated by the aqueous vapour it contains. A further slight reduction causes the air to deposit a portion of the aqueous vapour it contains on the surfaces of the bodies previously cooled by radiation. The temperature at which dew begins to be formed is called the *dew-point.* It varies with the degree of humidity of the atmosphere. One night it might be 41° F., and next night it might be 50°, though the temperature of the air on both nights might be about the same. The nearer, however, the air is to the point of saturation the sooner will the dew-point be reached. When the dew-point is below 32° the moisture deposited passes at once into the solid state, and is known as *hoar-frost* or *rime.*[1]

Various circumstances influence the production of dew. It is never abundant except during clear and calm nights. If the night be cloudy, the clouds reflect and radiate back the heat given off from the surface of the ground, so that the surface of the earth does not become sufficiently chilled. If the night is windy, the air near the surface is constantly being renewed, and is thus prevented from being reduced to the dew-point; though a slight wind is rather favourable than otherwise, because it gradually brings into contact with the cool surfaces fresh layers of air. Upon metallic substances, which are bad radiators, and on the hard beaten road, which quickly conducts heat from the strata beneath, little or no dew is deposited; while on blades of grass, twigs, leaves, wool, hair, and other such objects, which quickly lose the heat from their surfaces owing to being good radiators and bad conductors, a copious deposit of dew forms. But anything that checks the radiation, as a screen above or beside the object, prevents the formation of dew. It is also evident that the deposit of dew will be greater according as the air is more nearly saturated with vapour, for then the dew-point is sooner reached. Finally, dew is usually more abundant in spring and autumn, as the differences of temperature between day and night are greater than at other seasons, and the dew-point temperature is therefore more quickly and more certainly reached.

219. **Fogs and Mist.**—It sometimes happens that the aqueous vapour throughout a large space of the atmosphere near the surface of the earth becomes condensed into minute particles of water that remain suspended in the air. These visible particles form a kind of cloud near the surface, called fog or mist. A fog may arise when a current of warm and moist air comes into contact with water at a lower temperature, or by the intermixture of two masses of air, one of which has a lower temperature than the other. Thus a warm moist current of air passing over an iceberg may have some of its vapour precipitated as fog. The frequent fogs on the banks of Newfoundland are caused by the warm damp air that has passed over the Gulf Stream coming in contact with the cold air over the Arctic current that flows down through Davis Strait. Fogs are also often seen in low grassy bottoms or river valleys in the morning, but these are usually dispersed during the day as soon as the heat of the sun renders the air capable of taking up the moisture that has thus been condensed out of it. A mist is very similar to a fog, but the particles of moisture of which it consists are rather larger than those of a fog.[2]

220. **Clouds.**—Clouds are merely fog or mist formed in the higher strata of the air, where, as we have seen, the temperature is lower than

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[1] See account in Appendix, p. 306.

[2] Mr. J. Aitken has shown that the condensation of the aqueous vapour of the air, either as fog, mist, or cloud, nearly always takes place around the dust-particles, or other solid nucleus, floating in the air. Ordinary dry air has been shown to contain more than two millions of minute dust-particles in every cubic foot.

near the surface of the earth. Mist or fog is a cloud near the earth's surface; clouds are mists at a considerable height. As the warm moist air expands, it ascends and rises into colder regions, while the very act of expansion also lowers its temperature. The height at which the clouds float in the atmosphere varies much, the average height probably being between one and two miles. The thin light clouds are seen at the greatest heights, while thick dense clouds that are heavier only exist at a small distance above the earth. Clouds are not always composed of water particles, for the light fleecy clouds that float in the higher and colder regions are composed of small ice needles. This is certainly the state, as the intense cold at such great heights, from six to ten miles, is so great that water could not exist there in the liquid state. Besides, the icy condition of such clouds is also proved by the mode in which light is refracted in passing through them. The continually changing appearances of clouds are brought about by their movement, for they are continually descending into warmer or drier tracts of air, in which their moisture is often again dissolved.

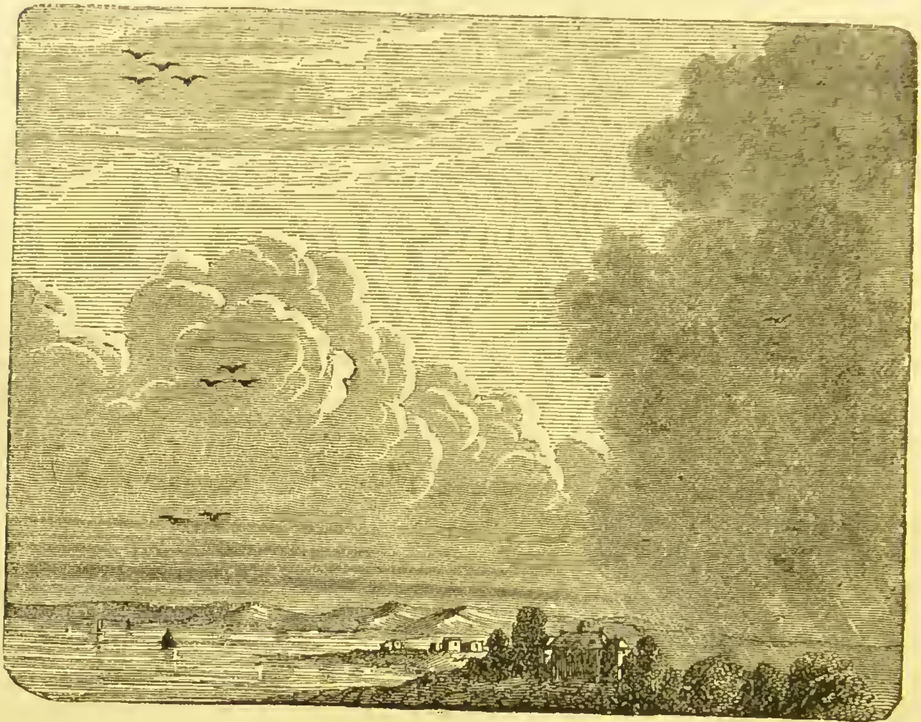


FIG. 91.—Varieties of Clouds.

Mr. Luke Howard has divided clouds into four chief varieties—the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*. These four kinds are shown in fig. 91, and are indicated respectively by one, two, three, and four birds on the wing.

The Cirrus (Lat. *cirrus*, a curl) is a whitish streaky cloud, having a feathery or fibrous appearance. These clouds are often called *mares' tails*, from their shape. They only exist at great heights, and it is these clouds which are believed to consist of ice particles. A cirrus cloud is often a sign of wind or a change of weather.

The Cumulus (Lat. *cumulus*, a heap) is a rounded or hemispherical cloud, often rising from a horizontal base. Hence it is sometimes called the *woolpack* cloud. The cumulus is the cloud of day, especially in summer, and is produced by an ascending current of warm air, the vapour of which is quickly condensed. Towards evening these clouds often lessen or entirely vanish. If, however, they become more numerous, especially with cirrus clouds above, a storm of rain may be looked for.

The Stratus (Lat. *stratum*, a covering or layer) is a widely extended continuous horizontal sheet, increasing from below upwards. It is generally a fine-weather cloud, and appears low down in the evenings and early mornings of the brightest days. It is indicated in the figure by two birds.

The Nimbus (Lat. *nimbus*, a dark rain-cloud) is a rain-cloud having no particular form, but usually of a dark uniform grey tint with fringed edges. It is the cloud into which the others resolve themselves when rain falls, and is therefore sometimes called *cumulo-cirro-stratus*. Other forms exist that are brought about by a combination of some of the preceding. One of these, called cirro-cumulus, is a high cloud consisting of small irregularly placed rounded masses, like a flock of sheep lying down, or like the markings on a mackerel, from which we get the name 'mackerel sky.'

221. **Rain.**—Of all the forms in which the water derived from the earth by the process of evaporation is restored again to its surface, rain is the most important. It is produced by the continuous condensation of the water vapour of the air, so that the minute particles that form clouds unite to form drops, which fall to the earth through the action of gravity. At great heights the raindrops are very small, but as they fall they generally increase in size, either by several joining together or by condensing on their cool surface the aqueous vapour of the strata of air through which they fall. This explains why the drops that fall from a thick mist are so small, the mist being nearer the surface of the earth. Occasionally, however, drops falling through warm dry air may become less in size, or even be completely evaporated before reaching the earth.

222. **The Rain Gauge.**—It is important to ascertain the *amount* of rainfall that occurs at any place. This should be done every day at a fixed time, and the daily amounts in a certain year when added together will give us the annual rainfall for that year. By taking the annual amounts for a number of years, and dividing by that number, an average annual rainfall for any given place may be ascertained. The instrument used to measure the rainfall is called a Rain Gauge. It consists of a copper funnel, the top of which has a certain area—20 square inches, for example—and the neck of which fits into a bottle, or, better, a cylindrical copper can. The funnel and bottle are then enclosed in a metal cylinder which is considerably taller than the funnel, so as to retain snow when it falls, and prevent it from being blown out (see fig. 92). The measurement of

the rainfall is made by pouring out the contents of the bottle into a glass measure which is marked to represent hundredths and tenths of an inch, and which is capable of holding ·50 inch of rain. Such a rain gauge is known as a Snowdon Gauge. If there be more than half an inch of rain, two or more measurements must be made. When snow falls, that which is collected in the funnel is melted and measured as rain. Roughly speaking, a depth of ten inches of snow is equal to one inch of rain. The rain gauge should be placed in an open situation, away from trees and buildings, and at a height of one foot from the ground. A 'rainy day' is one on which the rainfall is not less than ·01 inch. From what has been said above about the usual increase in the size of raindrops as they fall, it is plain that the amount of rain collected at the top of a high building will often be less than the amount collected near the surface of the ground. One inch of rain on a square yard gives 4·67 gallons, or 47·74 pounds; on an acre it corresponds to 22,662 gallons, or 100·99 tons. Remember, then, *one* inch on *one* acre gives 101 tons.

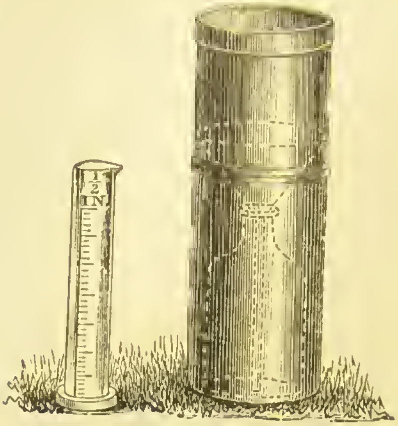
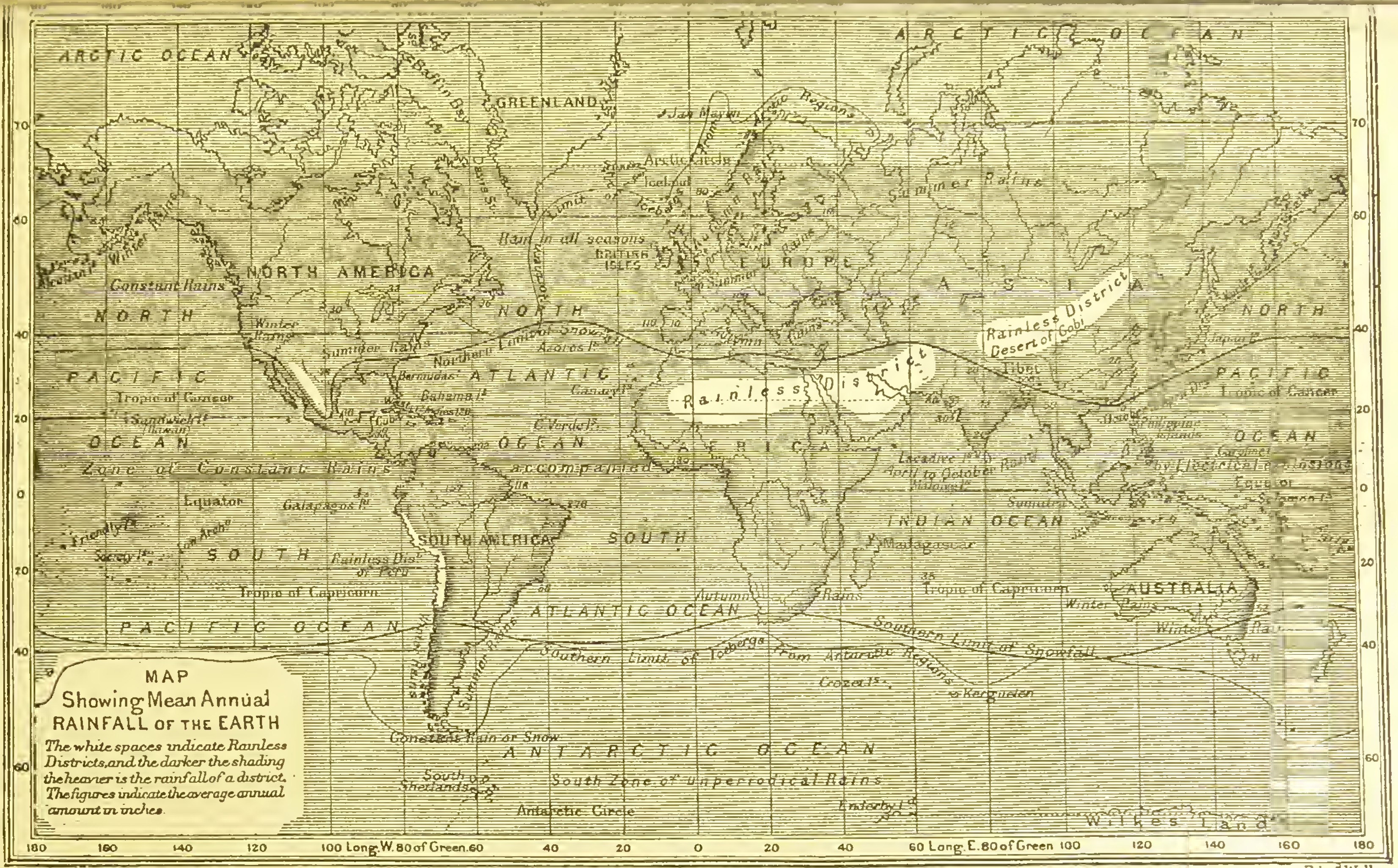


FIG. 92.—Rain Gauge.

223. **Distribution of Rain.**—On the accompanying map an attempt is made by means of shading to indicate the average annual amount of rain-fall on the various portions of the earth's surface, but it is not possible to indicate this accurately for all places, as our knowledge is not sufficiently complete. Still such a map is useful, and for all places where observations are regularly made it may be regarded as tolerably correct. Various circumstances affect the quantity of rain which falls in different countries. In all cases it is produced by the cooling of air more or less charged with aqueous vapour; and Mr. R. H. Scott gives us the three chief causes—'(1) The ascent of a current of damp air which is chilled by expansion as it rises. (2) The contact of damp and warm air with the colder surface of the ground, as in the case of our west coasts in winter, where the land is colder than the sea surface. (3) The mixture of masses of hot and cold air.'

The first cause comes into operation at and near the equator. There the temperature is high; and as the capacity of air for moisture greatly increases as the temperature increases, the rising and expanding air in tropical regions is chilled as it ascends, and we have a region of almost constant and heavy rain, often accompanied by violent thunderstorms. Speaking generally, the annual rainfall decreases from the equator to the poles. At St. Domingo it is 107·6 inches, at Havannah it is 91·2 inches; at Madeira, 27·7; at Bordeaux, 25·8; and at London, 23·5.

The second cause of rain is that to which the wet western coasts of Europe are mainly due. In Ireland, for example, the annual rainfall on the west coast is 45 inches; and on the west coast of Britain it is about 37 inches; while the rainfall on the east side is only about 24. But both the first and second causes contribute to this result on our west coasts; for though the south-westerly winds that come across the Atlantic are charged with water vapour, some of which is condensed in the lower layers by the colder sea-coast as they pass inland, yet it must be also noted that



Edwd Welles.

MAP VIII.

this coast is mountainous; and as the air is forced to ascend the sides of the mountains it becomes rarefied and chilled, so that the higher layers of air have their moisture condensed on the seaward slopes of our western hills. Hence we find that, as a general rule, rain is more abundant on the sea-coasts than in inland regions, and more abundant in mountainous districts than in the lowland regions. The wettest place in England is at Seathwaite, near the head of Borrowdale, in Cumberland. For six years it has had an average annual rainfall of 154 inches. Lincoln is the driest place, having a mean annual rainfall of only 20 inches. Bergen, on the west coast of Norway, has a mean annual rainfall of over 80 inches. In this country the rainfall seldom exceeds an inch in a day, though occasionally it has amounted to four inches. In tropical countries, however, it is sometimes from thirty to forty inches a day.

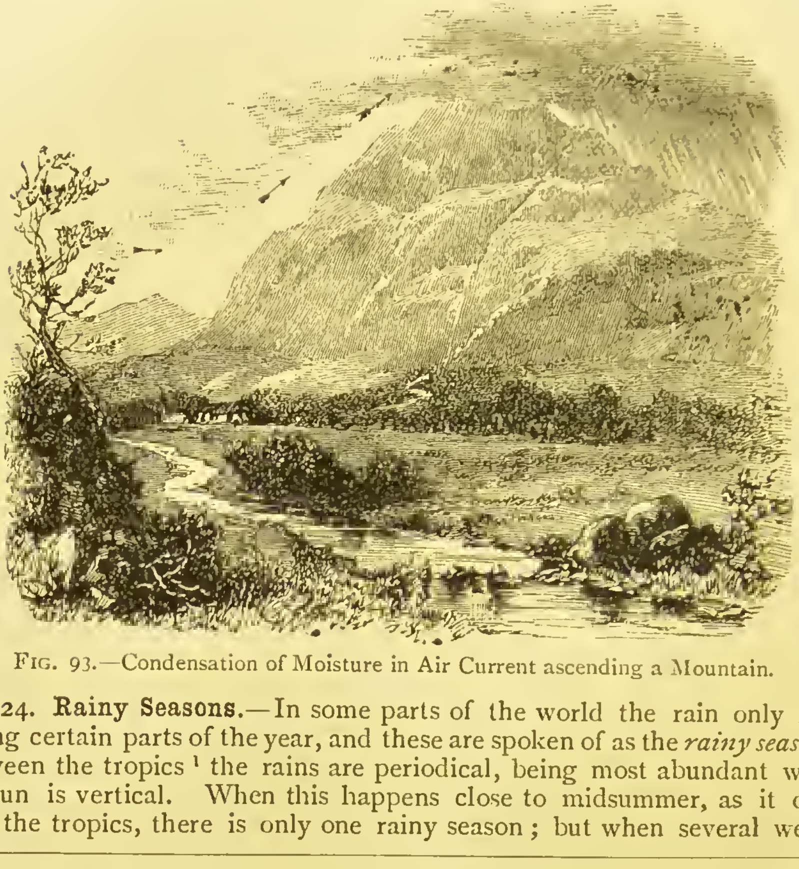


FIG. 93.—Condensation of Moisture in Air Current ascending a Mountain.

224. **Rainy Seasons.**—In some parts of the world the rain only falls during certain parts of the year, and these are spoken of as the *rainy seasons*. Between the tropics[1] the rains are periodical, being most abundant when the sun is vertical. When this happens close to midsummer, as it does near the tropics, there is only one rainy season; but when several weeks

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[1] The *tropics* (Gr. *trope*, a turning) are two circles drawn round the earth parallel to the equator, at a distance of $23\frac{1}{2}$ degrees on each side of it. The southern tropic, called the Tropic of Capricorn, has the sun vertically overhead on December 21. He then moves northward, and the sun is vertical at the northern tropic, called the Tropic of Cancer, on June 21. At all places between the tropics, that is, in the tropical or torrid zone, the sun is vertical twice during the year, but at places beyond the tropics the sun is never vertical. (See chapter on the Movements of the Earth.)

intervene between the times when the sun is directly overhead, as near the equator, there are two rainy seasons. In the districts where the monsoons prevail the rainy season depends on these winds. Thus in India and China, when the north-east monsoon is blowing from October to April, the east coasts receive the supply of rain; but most of the rain of India and the western coasts generally is chiefly brought by the south-west monsoons that blow from April to September. Outside the tropics, in higher latitudes, where the winds are variable, rain may occur at all seasons.

225. **Regions of Great Rainfall and Extreme Dryness.**—The regions of greatest rainfall are (1) parts of the equatorial regions of calms already described, and (2) certain districts where moisture-laden winds meet ranges of mountains and are forced to ascend. At Cherrapoongee, on the Khasia Hills, in Assam, at an elevation of more than 4,000 feet above the sea, the annual rainfall is said to be 560 inches. This is due to the condensation of the vapour brought by the winds called the south-west monsoons from over the Indian Ocean. These winds on rising to this height are cooled below their dew-point, and their great moisture is thus precipitated. On the Western Ghauts, near Bombay, there is also an annual rainfall of 260 inches, due to the same cause. At Valdivia, in Southern Chili, there is a heavy rainfall, 116 inches, brought by the westerly winds which there prevail; while on the same side of the Andes near the equator, where the south-east trade-winds continually blow, there is a rainless district in Peru. As these winds blow across the continent all their water vapour is deposited, and flows back again by rivers into the Atlantic, the last traces being extracted by the eastern sides of the lofty Andes that guard the western coast. Other rainless districts are the great tract of land stretching eastward from the Sahara through Egypt and Arabia to the Persian Desert, the Desert of Gobi, the Great Salt Lake region in the United States, and a part of the Kalahari Desert in South Africa. All these places are rainless because the winds have been deprived of their vapour during their passage over sheltering high ground, and descend on the lee side as hot dry winds. Thus the Desert of Gobi is shut off by the lofty Himalayas from receiving any of the moisture so abundantly brought to the southern slopes of these hills, and the north-east winds from the plain of Siberia are too cold to allow of any being brought by them. Even in the open ocean, in the districts exposed to the indraught of the trade-winds, which come from a colder to a warmer region, little or no rain falls. It may also be mentioned that rain is usually more abundant where vegetation is plentiful, the air being chilled by the leaves of trees and other plants. In some cases a region has been rendered dry and even barren by an unwise clearing of the forests.

226. **Snow.**—We have seen how, through the condensation produced by cold, the aqueous vapour of the atmosphere may be made to change its invisible gaseous form, and become the minute liquid particles of which fogs and mist consist, and how these particles may unite to form the drops which fall as rain. If, however, the air in which a cloud is formed is below freezing-point, the tiny water particles are frozen into crystals of ice of a regular geometrical form, being either hexagonal plates or six-rayed feathery stars. Snow consists of aqueous vapour solidified into icy particles, which cohere in regular symmetrical forms, having usually six rays or six sides. A number of such crystals usually cling together and fall as snowflakes. They may be examined by letting them fall on the sleeve of a dark coat, and viewing them through a magnifying lens. Many varieties of

these snow crystals have been observed, some of which are shown in the annexed figure. They are all formed so that the angles made by the rays bear a close relation to those of a regular hexagon, viz. 60°. Their white appearance is due partly to enclosed air particles, and partly to the reflection of light at their numerous surfaces. Examined by a lens, each little crystal is seen to consist of transparent ice.

Snow does not fall in all parts of the earth at the sea level. It is never seen, for example, between the tropics; for even if it were formed in the higher regions of the atmosphere, it would melt as it passed through the warmer strata near the sea level. A line showing the limit of snowfall at the level of the sea is traced on the map showing the distribution of rain, and from this we see that it seldom reaches the limit of 15° from the tropics, and that the limit is more remote from the equator in the Southern than in the Northern Hemisphere.

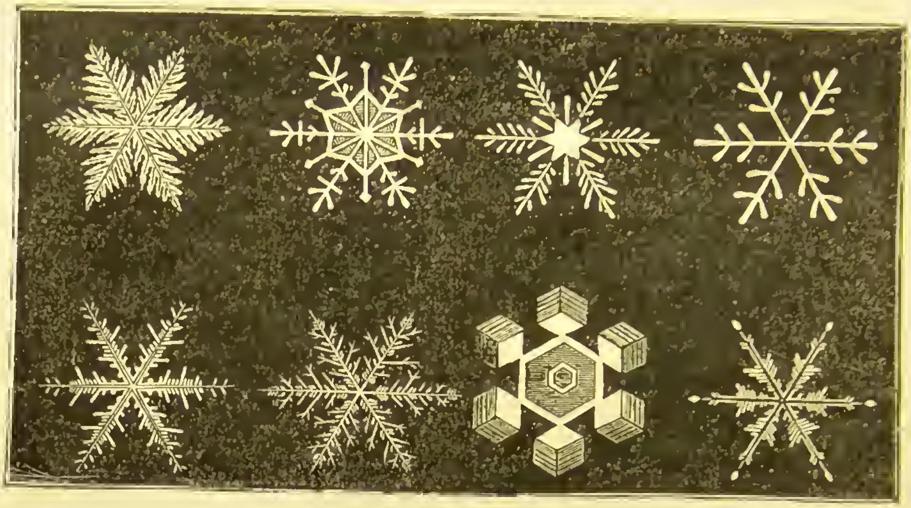

FIG. 94.—Snow Crystals.

227. **Snow-line.**—But although the snow does not fall at the sea level in all parts of the world, yet it is found, owing to the diminution of temperature with increasing height, at certain elevations in all parts. The high peaks of the Andes near the equator stretch so far into the upper and colder regions of the air, that they are perpetually covered with a snowy mantle. *The snow-line, or limit of perpetual snow, is that line below which the solar heat of summer is sufficient to melt all the snow that falls, but above which more snow falls than the heat of the summer can melt.* This line takes the form of a curve, which starts at a height of about 16,000 feet at the equator, and gradually descends to the sea level near the poles. Thus at Quito, near the equator, the limit is 15,800 feet; on the high

peaks of Mexico, 14,800 feet; in Spain, 11,200 feet; on the Alps, between 8,000 and 9,000 feet; on Dovre Fjeld Mountains in Norway, 4,000 feet; at the North Cape, only a little above 2,000 feet; and at Spitzbergen, near the level of the sea. The highest mountain in Britain, Ben Nevis, 4,400 feet, is a little below the snow-line, though snow may remain through some of the summers in sheltered hollows. But the height of the snow-line does not depend entirely on latitude. It varies with the character of the prevailing winds, with the greater or less dryness of the air, and with the volume of snow that falls during the year. It is lower, for instance, on the moister and warmer south slope of the Himalayas than on the far colder but drier north slope of these mountains. It is 16,000 feet on the south slope, and 20,000 feet on the north slope. On the northern side of the Alps it is about 8,000 feet; but on the southern side, which receives more sun and warmer winds, it is 8,800 feet.

The snow which falls below the snow-line dissolves, and soon adds to the water supply of a country; but that which falls above the line produces ice-caps, névé, and glaciers, which will shortly be described. *Sleet* is a mixture of melting snow and rain. *Hail* consists of hard pellets of ice which fall through the atmosphere in showers. These pellets are sometimes simple rounded masses; sometimes they are of an irregular shape, and formed of concentric layers of ice round a core. How they are produced is not definitely known. Hailstones vary in size from a small pea to a hen's egg. In our climate they fall principally in spring and summer and often precede a storm.

228. From what has been said it will be seen that there is a continual circulation of the water of the globe. By the agency of the sun's heat immense quantities of water are continually being taken up into the atmosphere in the state of vapour. For a time this remains invisible, but by condensation it is at last brought into a visible condition as cloud or mist, and the clouds by further condensation discharge their contents chiefly as rain. It has been calculated that in our country about one-third of the rain that falls on the land is at once evaporated again, another third is absorbed by the rocks, and after a longer or shorter course beneath the surface for variable lengths of time this portion again comes to light in springs. The other third flows off at once into the rivers, where, indeed, the spring water also ultimately goes. Rivers pour their contents into the sea, and from the surface of both rivers and sea evaporation takes place, and the water sets off on another round. Professor Dove compared the atmosphere to a vast still, of which the sun is the fire and the sea the boiler. The cool air of the higher parts of the atmosphere and of the colder zones acts the part of a condenser, and on a wet day the liquid distils over as rain.

CHAPTER XII.

THE SCULPTURE OF THE LAND.

Action of Air, Rain, Springs, Rivers, and Glaciers on the Earth's Crust.

229. THE rocks described in a previous chapter are constantly being worn away by various destructive agents acting upon them, and the present outline of the earth's surface is not that which has always been, nor is it that which will continue. We have already pointed out how the sea is continually at work wearing back the rocks of the coast, and reducing the material broken off to a finer and finer state, and how this is carried out to some distance beyond the lowest tides. Here its work of destruction ceases, for the depths of the ocean are not disturbed by the movements of the waves on the surface. But other agents besides the sea are at work on all the exposed parts of the land surface, and it is of these agents that we shall now briefly speak. The general process by which the surfaces of rocks are broken asunder and the loosened material carried away so as to expose the parts previously covered is called *denudation* (Lat. *denudo*, I lay bare). *Erosion* (Lat. *rodo*, I gnaw) and *disintegration* are other words applied to the breaking up and crumbling of rocks, and the loose material arising from this waste is often spoken of as *débris* or *detritus*. Débris is a French word adopted into English, and means *ruins*, or *remains*; while detritus means literally *matter rubbed off*.

230. **Action of the Atmosphere.**—This has already been referred to in speaking of the 'weathering' of rocks. The oxygen of the air is ever entering into new combinations with those rock constituents for which it has an affinity, and in this it is assisted by the moisture of the air, which also contains the same element. By this union of the oxygen with the different bases of rocks, changes of colour, as well as a breaking up of the surface of the rocks, is often produced. Thus rocks containing the protoxide of iron (FeO) often have a greenish colour; but when the iron unites with more oxygen to form the sesquioxide (Fe_2O_3) the rock is disintegrated, and the new compound of iron gives a red or brown colour to the material formed. Another atmospheric influence is the varying heat at different times, the alternate expansions and contractions thus produced tending to loosen the particles on the surface of the rocks. The action of the carbonic acid of the atmosphere has been already mentioned. This

compound tends to form soluble combinations with the magnesia, lime, and potash in the different varieties of felspar, and the mineral then produces the white clayey substance called kaolin (par. 118). The power of water containing CO_2 in solution to dissolve calcareous rocks has been often referred to (see par. 132).

231. **Action of Rain.**—The action of rain on the rocks of the earth's crust is both *chemical* and *mechanical*. In passing through the air it dissolves small quantities of oxygen and carbonic acid, and after reaching the ground it obtains a further supply of carbonic acid from decaying animal and vegetable matter. How this oxygen and carbonic acid assist in disintegrating rocks has already been described, and it is this general action of the gases contained in the air or dissolved in water, assisted by the heat of the sun, and especially by *frost*, that is referred to under the word 'weathering.' The loosened material on the surface of rocks produced by this 'weathering' is then carried away either by the mechanical action of the rain or wind, particularly from the exposed faces of cliffs and the sides of hills. The smaller materials are carried farthest, while the larger pieces are left behind to undergo further disintegration. The softer parts of the rocks suffer most from this action of the weather and the mechanical force exerted by rain, and thus are produced irregular surfaces, the more easily attacked portions giving rise to hollows and the harder to projecting pieces. The natural division of the rocks into cubical masses by the joints or cracks greatly assists in this work of disintegration.

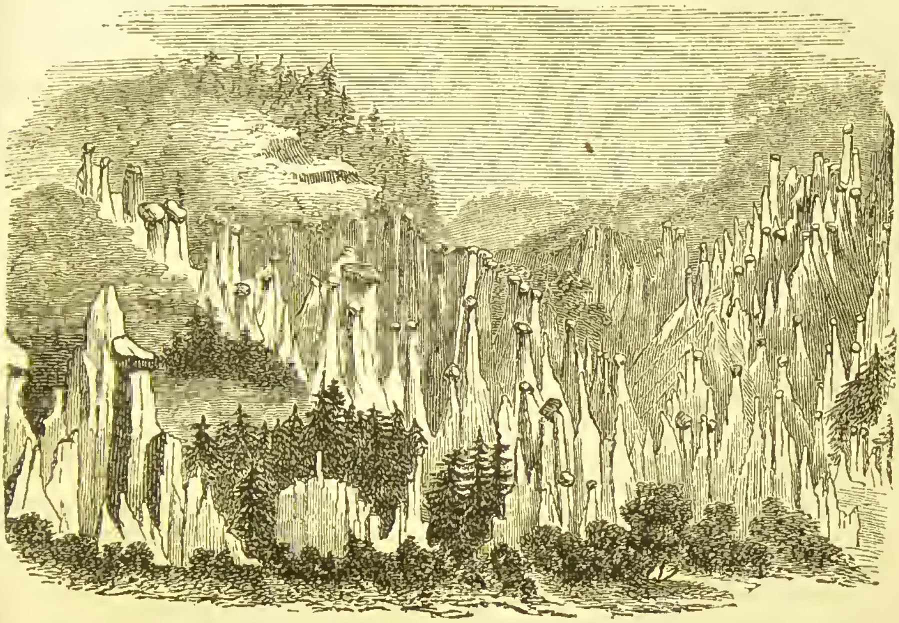

FIG. 95.—Earth Pyramids in the Tyrol.

Every one has noticed the small impressions made by the raindrops on the surface of sand and mud, and it has sometimes happened that these have been preserved in the rocks for thousands of years. But more striking effects of the power of rain are often seen in the natural arches and conical pillars of earth capped by a block of stone which are found in the Tyrol, the western States o. America, and other districts. These have been produced by the prolonged action of the rain. Imagine a valley or depression filled with loose earth or clay, through which blocks of stone are scattered at various depths. The pattering rain, assisted by the tiny streams that form, loosens the material and transports it to a lower level, but each block of stone protects the part it covers, so that at last when the surrounding portions are removed, a number of conical pyramids of earth remain as monuments of the extent of erosion that has been produced.

232. **Work of Rivers.**—The land area from which a river and its tributaries collect their water is called its *catchment basin* ; the land which separates adjoining basins is called a *water-parting*, and the slopes down which the water runs is called a *watershed.* The *source* of a river is to be found in some little rill or spring on the slopes of a hill, and the water of which it consists has descended from the clouds in the form of rain or snow. This water gathers at first into tiny rivulets, and these, as they descend, are joined by many others ; a rivulet is formed, which receives many tributaries, and thus there is produced a common stream, often of great size, which carries down a huge volume of water into the sea. This may again be taken up into the air by the process of evaporation, may again form clouds, which discharge their contents on the earth, and thus the continual circulation of which we have previously spoken goes on.

233. **Valley-making.**—As an active agent in altering the surface of the earth a river effects erosion of its bed and banks, and transport of material in one part of its course, while in another part it deposits this material. In the upper part, where the fall or slope is steep, the river carries down sand and stones, the lighter and smaller particles being carried furthest. In times of flood the torrents of rushing water on a mountain slope tear up the rocks, hurling them down the stream, and make deep trenches on the mountain slopes.

In some parts of the rocky beds of rushing streams the eddies produced in the water cause a number of stones and sand grains to revolve, and these form smooth rounded cavities called *pot-holes*. Pot-holes are often seen several feet deep. The fragments of rock torn away by the rushing waters aid in breaking off other portions, and by continual rubbing and pushing along have their sharp corners broken off, so as to become rounded into smooth pebbles.

The particles held in suspension in the water, and which settle down as it becomes stiller, are called *sediment* ; and the more disturbed the water is, the larger are the particles forming the sediment. But besides acting as carriers of sediment, rivers also carry large amounts of matter *dissolved* from the rocks over which the water has run. Thus the waters of the Nile contain in solution 14 parts of mineral matter in 10,000, those of the Rhine 17, and those of the Thames 40.

Many of the great valleys of the world have been excavated by rivers. These river valleys are of various shapes, sometimes being deep and narrow, when they are called *gorges* or *ravines*, but at other times wide and comparatively shallow. The action of the flowing water is greatly assisted by the earth and stones carried along by the stream, the running stream itself having but little abrading power. These rub against the bottom and sides of the channel, and thus carry on the work of wearing away the bed and the sides of the stream. We can thus understand the following description of Professor Green :—‘ Rivers are denuding tools, which tend to cut steep-sided trenches across a country ; and these trenches they are continually deepening as long as they have sufficient fall.' That many river valleys have not this sharply defined appearance is due to the fact that the various other denuding agents mentioned above have been at work on the sides of the stream wearing away the rocks and widening the valleys, especially where the banks are formed of soft rock. The inclination of the strata also assists in

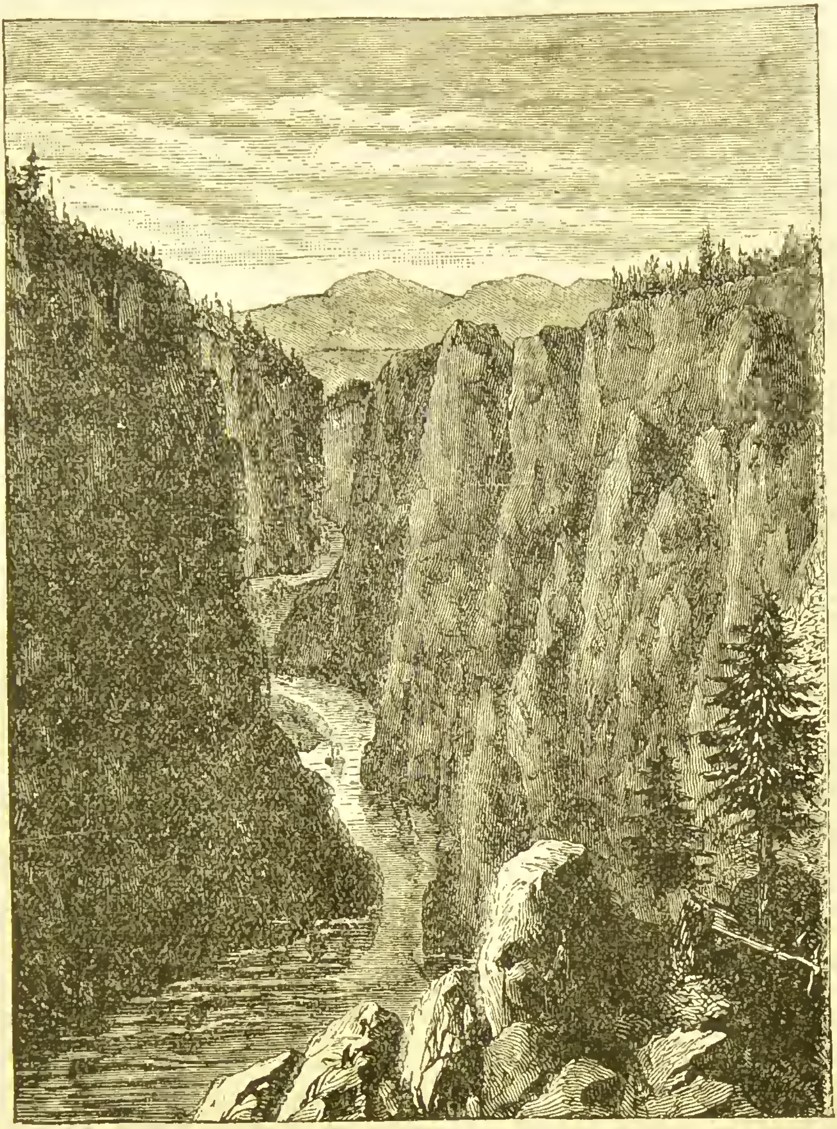

Fig. 95.—A Cañon in the Colorado District.

determining the shape of the valley. When we look at the river trenches formed in a district where rocks lie in horizontal beds, and where there is little or no rain to wear away the flanks of the river gorge, we see the above description of a river trench is true. Magnificent examples of such deep gorges worn by rivers, and called cañons, are seen in the course of the river

Colorado and its tributaries. Here the main stream flows for about 300 miles through a chasm from 150 to 500 yards wide in most places, with a depth varying from 3,000 to 6,000 feet. On each side of this Great Cañon are numerous other cañons, at the bottom of which tributary streams either now run, or once have run. These great chasms are the result of river erosion, and have been worn out of the high and arid table-land of this marvellous region.

That these mighty gaps have been formed mainly by the action of the rivers is plainly proved by the fact that the beds on each side of the cañons correspond perfectly, and also by there being no signs of fissures or rents produced by any convulsion of the land. In some places the vertical walls of the cañons reach quite up to the table-land above; at other places the walls present inclined slopes on which gigantic earth-pillars resembling towers, pinnacles, buttresses, &c., have been formed in the way previously described.

Many ravines have been formed by the slow retrocession of the waterfalls that occur in the beds of some rivers. Such has been the origin of the deep trench that stretches a distance of seven miles from Queenstown to the Niagara Falls. This ravine has a breadth varying from 200 to 400 feet, with almost perpendicular walls, which terminate suddenly in the escarpment or heights seen at Queenstown, where the falls are believed to have first been situated. On looking at the figure it will be seen that the falls take place from the edge of hard limestone rocks, and that these rocks overlie beds of shale, which is a much softer material. These soft shales are being continually crumbled away and removed by the spray that rises from the pool at the foot. The projecting limestone thus undermined falls down at various intervals, and thus the position of the falls is continually retreating.

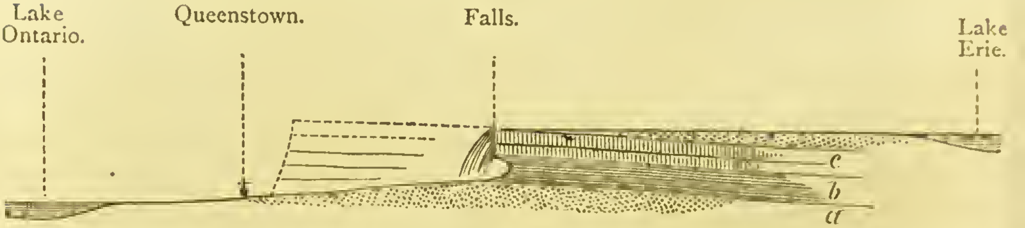

FIG. 97.—Section showing the Rocks at the Falls of Niagara. *a*, sandstone ; *b*, shale ; *c*, beds of limestone.

It is even possible to form some idea of the time taken to cut out the gorge. Recent inquiries have shown that the rate of retrocession is probably between four and five feet per annum, and if we divide the length of the gorge by four, we get between 9,000 and 10,000 years as the time during which it has been forming.

234. **Longitudinal and Transverse Valleys.**—Mountain chains usually run in one general direction ; and though they may give off lateral ridges, the chief peaks coincide more or less with the axis of the main chains. In several cases we find nearly parallel ranges separated by a depression or valley, whose bend coincides with the general direction of the mountain chains.

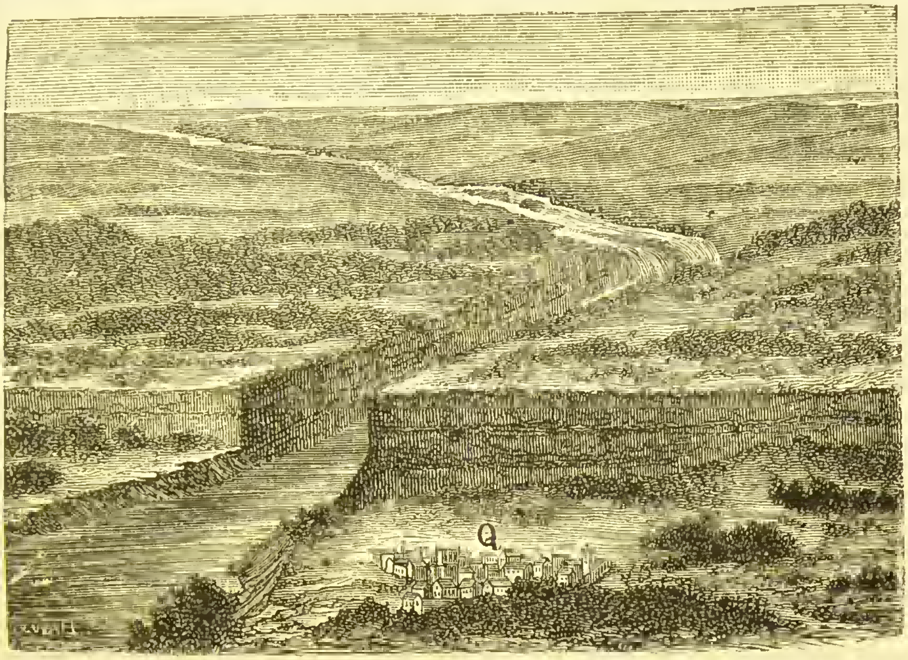

FIG. 98.—Bird's-eye View of the River and Falls at Niagara.

Such a valley between two parallel ranges is called a *longitudinal valley*. Thus the Rhone flows from its source in a glacier of St. Gothard to Martigny in the longitudinal valley between the Bernese Alps on the north and the Italian Alps (Lepontine and Pennine) on the south. Transverse valleys run more or less at right angles to the mountain chains. They are often deeply entrenched by the mountain torrents that run down their slopes and act as feeders of the main stream that runs in the longitudinal valley (see fig. 99). The tops of two adjacent transverse valleys often lie between two peaks, the depressions between which form a *col* or *pass* to the opposite side of the mountain chain. Longitudinal valleys are usually longer, have less descent and more gentle streams than transverse valleys.

235. **Alluvium and River Terraces.**—When a river traverses a wide valley it may in times of flood overflow its banks, and the spreading water,

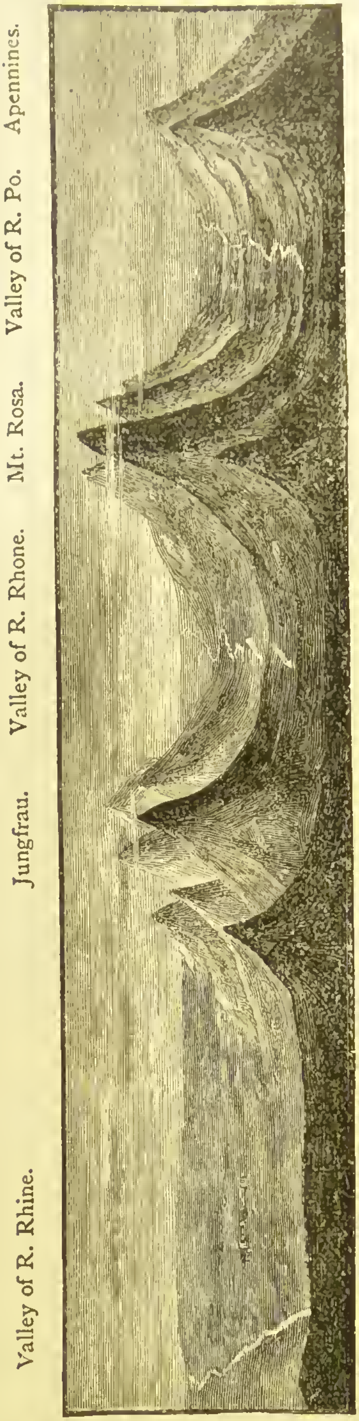
Valley of R. Rhine.
Jungfrau.
Valley of R. Rhone.
Mt. Rosa.
Valley of R. Po.
Apennines.

FIG. 99.—Longitudinal and Transverse Valleys.

losing its velocity, deposits on the tracts of land over which it extends, silt, mud, sand, and gravel, mixed at times with twigs, leaves, and bones.

The matter washed down and deposited on the sides of the river in this way is called *alluvium* (Lat. *luo*, I wash). Alluvial soils are thus formed on the districts bordering a river, and the edge of the alluvial plain is generally at the level of the highest floods. The height of this plain is at first increased by successive floods, but as the river deepens its channel the flood can no longer reach its first height, part of the old alluvium is cut into, and a new flood-plain is formed at a lower level. In this way the river valley comes to show a series of terraces formed of alluvium. These terraces of mud, sand, and gravel are often spoken of as *river terraces.* These alluvial terraces are seldom found complete on both sides of a river at the same place, as, owing to the serpentine course of many streams, the banks are often eroded on the concave side, and deposits made only on the convex lower banks (see fig. 117).

236. **Delta Formation.**—In the lower part of the course of a river the velocity of the stream has generally become so much diminished that deposition of sediment exceeds erosion. This takes place in particular where the flow is checked by the sea or lake into which a river empties itself. Here a large part of the sand and mud is deposited, and where the tides are small and the currents feeble this accumulates, so that in time the matter thus brought down rises above the sea level. In this way the river slowly fills up the bay or gulf into which it discharges itself, and a triangular deposit of low flat alluvial soil, called a *Delta*, is formed. It is so named from its resemblance to the Greek letter Δ, delta. The delta begins at the point where the waters laden with mud first met the sea in times long past; and from this point, called the *head* of the delta, it gradually widens, growing outwards and upwards year after year. It is made up of the successive layers of detritus brought down by the stream; and the shorter and more rapid the course of the river, the larger and coarser is the sediment forming this detritus. In times of flood, too, the particles will be larger

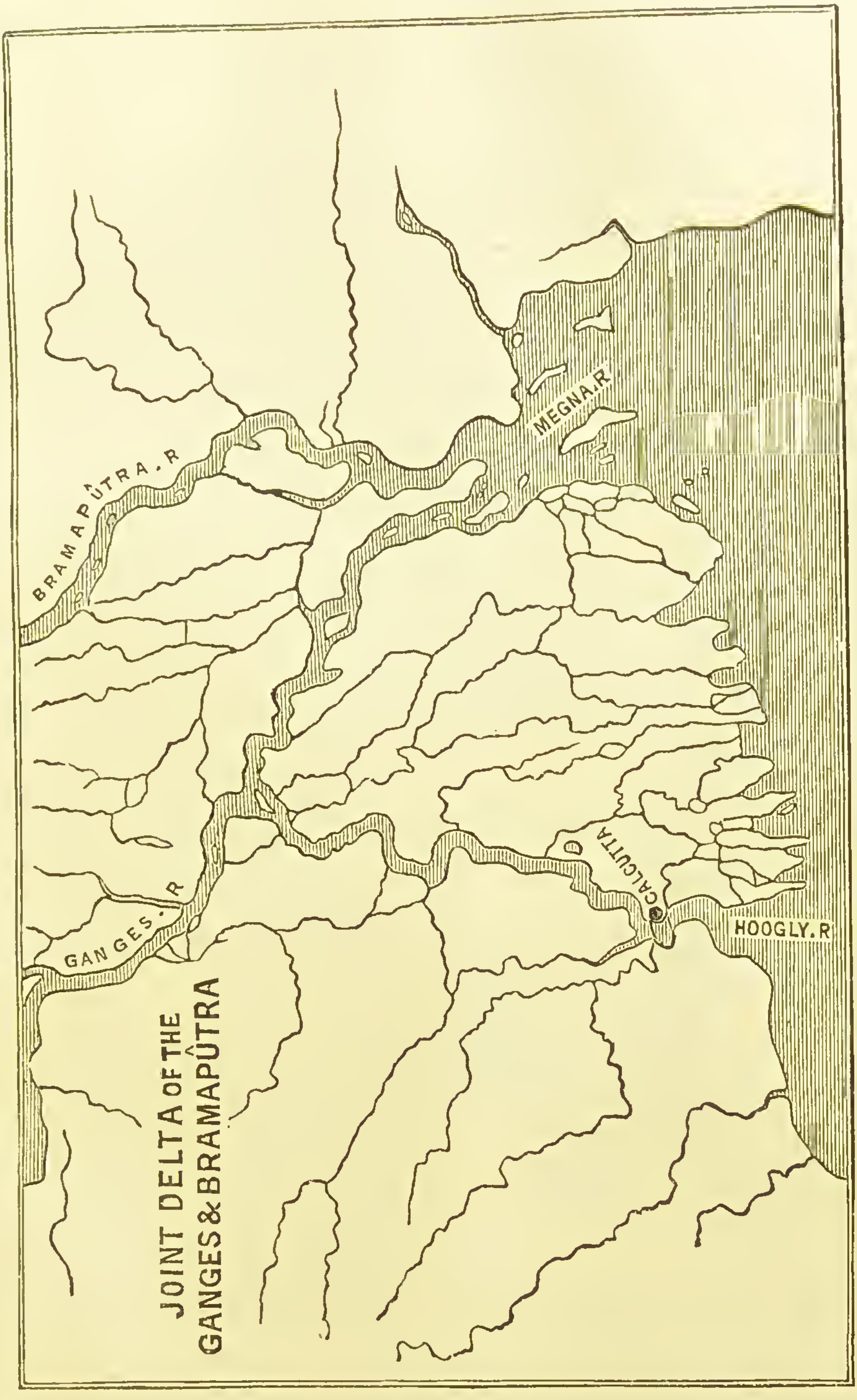
BRAMAPÛTRA.R
MEGNA.R
GANGES.R
CALCUTTA
HOOGLY.R
JOINT DELTA OF THE GANGES & BRAMAPÛTRA

FIG. 100.

than at other times. The main stream usually splits up into many branches, which traverse the accumulations brought down, and these various channels form a regular network of streams, which sometimes shift their directions, owing to some being silted up and new ones being formed. Among the well-known deltas are those of the Ganges and Brahmapûtra, the Mississippi, the Nile, the Rhine, the Rhone, and the Po. The Ganges has its source in a mountain stream issuing from a glacier in the Himalayas, at a height of 13,800 feet above the sea. During the first 200 miles of its course it falls 12,000 feet, and has almost the speed of a torrent; but after this it flows more quietly for over 1,700 miles, when it discharges its waters by many branches into the Bay of Bengal. During its course it receives a vast multitude of tributaries, twelve of which are greater than the Rhine. It has been computed that the average discharge of water by this river exceeds 200,000 cubic feet per second, and during floods it is said to contain $\frac{1}{428}$ part of its weight of matter in suspension. It would thus cover with sediment an area of 2,276 square miles to a depth of one inch every year. The apex or head of the delta is 200 miles from the sea, and the whole delta has an area of over 8,000 square miles. At Calcutta a boring has been made through the delta deposit to a depth of 481 feet without reaching the bottom. The deposit was seen to consist of sand, clay, pebble-beds, and some vegetable remains. The delta of the Ganges is joined by the delta formed by the still larger river Brahmapûtra, and the union of these two immense deltas is shown in fig. 100. From the mouth of the main branch of the Ganges, the Hoogly River, to the mouth of the main branch of the Brahmapûtra, the Megna River, there is a sea front of 220 miles, and the area of the united deltas is nearly equal to that of Ireland. In this delta the land near the sea is mostly a swampy marsh, covered with a rich vegetation of mangroves, nipa-palms, &c.; while beyond the margin of the land for some distance there are numerous shoals and sand-banks. As more sediment is brought down the marshy sunderbunds will rise higher and become habitable, and the shoals and sand-banks will be changed into marshy land forming a seaward extension of the delta.

The quantity of sediment brought down by the Mississippi is even greater than that brought down by the Ganges. It has long ago filled up the bay into which it first flowed, and is now sending out tongues of land into the Gulf of Mexico, and advancing at the rate of about 300 feet annually. The whole area of this delta exceeds 12,000 square miles, of which one third is sea-marsh. The goosefoot-like head of this delta presents a striking contrast to those of the Ganges and the Nile.

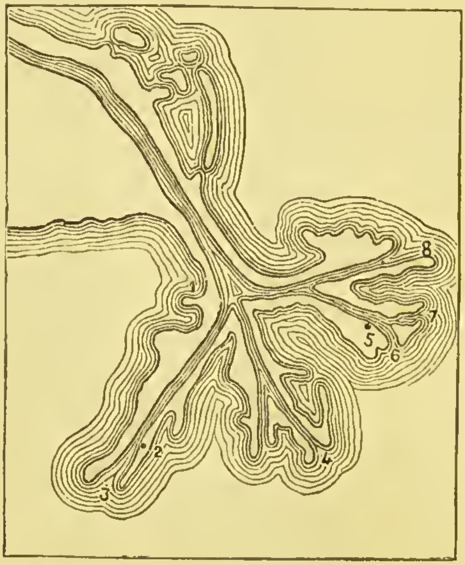

FIG. 101.—Lower Portion of Delta of Mississippi. 3, 4, 6, 7, and 8, channels.

The Nile delta has the general typical form of most deltas, and the head of the delta at Cairo is 85 miles from the coast (see a map of Lower Egypt). In times of flood, which happens during the rainy season in Abyssinia and the interior, the river is charged with sediment, but owing to the annual overflow the greater part of this sediment is deposited as a thin fertilising layer in Lower Egypt, so that comparatively little is now carried out to sea. Even that which is carried out is swept away by a Mediterranean current, so that there has been no extension of this old delta for over 2,000 years.

The Rhine delta forms the greater part of Holland. For a time this river was able to deposit its sediment near the mouth without the currents taking it away, but after advancing a certain distance the movements of the sea were strong enough to remove nearly all the sediment as fast as it was brought, and but little further growth takes place. The North Sea has, indeed, reclaimed from the Rhine delta the large space now occupied by the Zuyder Zee. The Po carries down in flood-times $\frac{1}{300}$ part by weight of solid matter, and has formed deposits that reach out into the sea for 21 miles. It is now being increased at the rate of 300 feet a year. Venice, Ravenna, and other towns stand on the delta formed by this river and the adjoining streams. Wells sunk through the deposits at Venice show that they are at least 566 feet thick. The Rhone forms a delta at its mouth which is rapidly increasing. Arles, where the river bifurcates, was 14 miles from the sea in 400 B.C. It is now 30 miles distant. The Rhone also forms another delta, not in the sea, but in a lake through which it flows ; for rivers flowing through lakes deposit a fan-shaped mass of sediment which forms a delta, the lake acting as a sieve to strain off the suspened particles travelling in the water. Thus the river Rhone enters the Lake of Geneva as a swift and turbid stream, but on leaving it at the other end the waters are quite blue, clear, and transparent. An ancient Roman town, now called Port Vallais, and once situated at the water's edge, is at this time more than half a mile inland. Hence the intervening alluvial tract must have been deposited during the last 1,800 years.

Such a delta is called a *lacustrine* delta (Lat. *lacus*, a lake). Lakes into which rivers flow are thus being contracted at their upper ends, and are slowly being filled up by the sediment which the river transports.

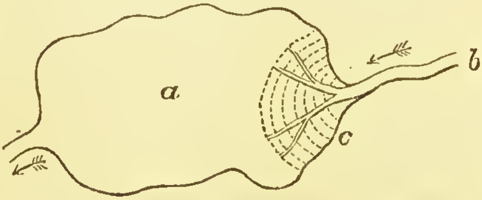

Fig. 102.—Stream running into a Lake and forming a Delta.

In the district occupied by the delta the sand and silt are deposited most abundantly on the margins of the river channels, and thus the banks are raised higher than the general plain. The banks of the Po and other deltaic rivers in the lower parts of their course have been further raised artificially in order to preserve the country from flooding. As the river deposits on its bed, this may even rise till the level of the water is above that of the surrounding country. Should the river burst its banks great damage and destruction of property follow. Fig. 103 shows a section of a river in a delta, and is very different from that of the stream when flowing through the valley in the higher parts of its course.

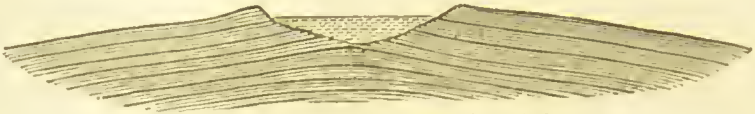

FIG. 103.—Section of River in a Delta.

Every river does not form a delta at its mouth even when it brings down plenty of sediment. Where the coast-line near the mouth is steep, where the sea is deep, and the velocity of the stream great, or where there are powerful tidal currents, no delta is formed. Thus the Thames forms no delta, although it brings down every year a large quantity of sediment. Much of this is deposited near the mouth, particularly during the rise of the tide, when the downward current of the stream is arrested. But as the tide flows out it assists the river current itself in sweeping away the previous deposit. The conflicting currents in the estuary or tidal part of a river often give rise to *shoals* and *sand-banks*, the sediment being swept away in one part and gathered together in other parts. At times the ponding back of the waters by each rise of the tide in the mouth of a river causes the deposition of the sediment to take the form of a line of accumulated material across the course of the river, known as a *bar*.

237. **Springs.**—As about one-third of the water that falls as rain sinks into the ground, it is necessary to inquire what becomes of this portion. Some kinds of rocks are said to be permeable, but other kinds are almost impermeable, and the water falling on these quickly runs off the surface unless they are traversed by fissures. Among permeable rocks may be mentioned gravel, loose sand, sandstone, and chalk; whilst clay, granite, basalt, and slate are nearly impermeable. Even among those rocks which are pervious the quantity as well as the rate at which the water passes through is very variable. In valleys where the strata are nearly all impermeable the rainfall runs off very quickly, and gives rise to floods in rainy weather, while the rivers become dry in fine weather. Where there is a fair proportion of permeable strata through which the water can

pass, an almost constant supply is furnished to the rivers. For, however deep this water may sink, either through a porous rock or through the branching fissures of other rocks, it is almost wholly stopped at last by an impermeable stratum. It then finds its way along the junction of the permeable and impermeable strata till it reaches an outlet at the surface in the form of a *spring*. Springs thus serve to drain the porous rocks that lie above them, and are always found at a lower level than the ground from which their supply of water is derived. They are met with in all parts of the world, in valleys, near the tops of hills, on the hill-sides, in caverns, and even under water. Some flow forth naturally, while others have been formed after artificial boring through the superficial strata. Where the water comes from a great depth it is warm, and as warm water can dissolve more mineral matter than cold water, such hot springs are always richer in dissolved salts than cold ones.

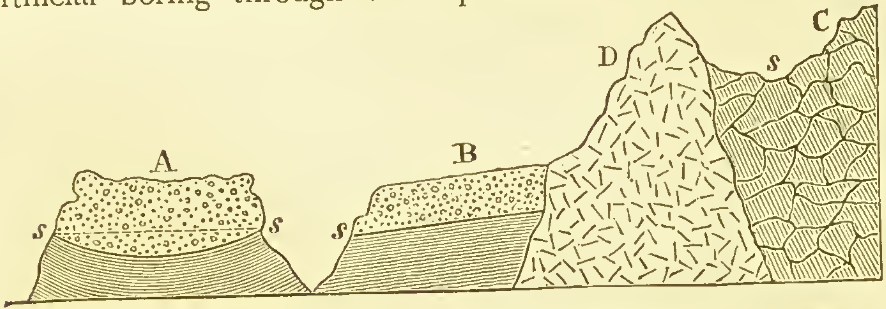

FIG. 104.—A, B, porous rocks; C, a rock with inter-ramifying fissures; *s*, *s*, surface springs. D, non-porous rock.

238. **Surface Springs.**—In surface springs the water simply falls down through the rocks by the action of gravity, and after going through its underground course comes out at the surface in some depression at the junction of a porous and impervious layer (see fig. 104, A and B). The point at which the water flows out is often determined by the inclination or *dip* of the strata, the amount of dip being measured by the angle which the surface of the bed makes with a horizontal line. It is evident that, as the water passes through the porous rocks above, it will sink until it reaches the impermeable rocks, and then flow along in the direction of the dip or inclination until the strata come to light in a valley or the side of a hill. Hence such surface springs are also called *dip springs* (see *s* in A and B). Of course, the upper pervious layer will only hold a certain amount of water, and when it becomes saturated to the top the water will run off at the surface.

239. **Deep-seated Springs.**—In deep-seated springs the water has sunk through the joints and crevices which are found in most rocks to a considerable depth. Then, not being able to get any lower, the pressure of the water behind and above forces it up through some fracture or fissure

opening upwards till it reaches the surface. These springs may be found either in a valley, or at a considerable height on a hill. They are fed by the distant strata, and the water having passed through the cracks and fissures of its underground course comes to the surface by pressure. Thus in fig. 104 the water that passes through the crevices of the rocks at the higher part C may pass down to a great depth; but when these rocks become full the water is forced up at the lower point *s*. Such a deep-seated spring may also rise at the junction of a water-bearing rock with a compact impervious rock.

240. **Artesian Wells.**—An important class of artificial springs or wells is known as *Artesian Wells.* Where bent pervious beds of rock lie between two bent impervious beds, so as to make a basin-shaped depression, lower in the middle than at the edges, the rain which sinks into the pervious rock where it reaches the surface will begin to gather in the central part of the porous rock as in a reservoir. If a hole be now bored in the hollow of the upper impervious bed till it reaches the water-bearing stratum, the water will well out at the top. The section shown in fig. 105 illustrates the arrangement of strata necessary to produce such a well. The water thus obtained may have fallen a distance of many miles several months previously, and if the gathering-ground be high the issue at the well may be forced by the pressure of the water behind to a considerable height. London and Paris are both situated in such basin-like depressions. Some of the water in London is obtained by boring through the upper layer of what is called London clay till the Tertiary sand or chalk is reached. When such water-bearing strata are not tapped artificially the water will at last overflow as a natural spring. It has been calculated that the water which falls on the chalk hills in Hertfordshire takes about sixteen months to travel to its outlet in the springs that feed the river Lea.

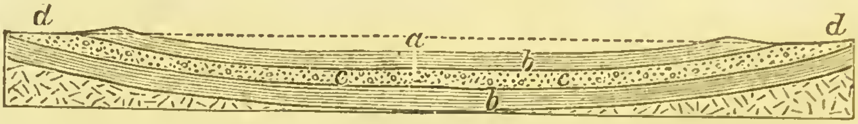

FIG. 105.—*a*, artesian well; *b*, *b*, impermeable strata; *c*, *c*, porous stratum; *d*, *d*, collecting surfaces.

241. **Thermal and Mineral Springs.**—Springs of heated water are known as thermal springs. Springs which hold an unusual quantity of mineral matter in solution are called

mineral springs. Ordinary spring water contains from 60 to 500 parts of mineral matter in 1,000,000. As thermal springs usually contain dissolved in them mineral substances not held in solution by springs of cold water, they are generally mineral springs also. The temperature of such springs depends on the depth from which the waters rise. There is a boring near Berlin to a depth of 4,172 feet, and the water which rises has a temperature of 110° F. As several natural springs have a much higher temperature, we may assume that they rise from a still greater depth. Thus the waters at Carlsbad have a temperature of 150° F. Mineral springs are of several kinds :—

(1) Those having in solution an oxide of iron and possessing an inky taste are known as *ferruginous* or *chalybeate* springs.

(2) *Calcareous* springs, which are abundant in limestone and chalk districts, are those which have dissolved much carbonate of lime (see par. 132).

(3) *Brine* springs contain a large proportion of common salt in solution. They occur at Nantwich, Droitwich, &c.

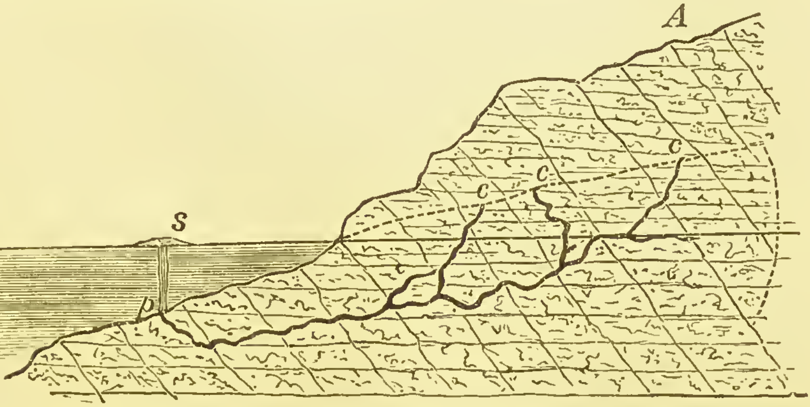

Fig. 106.—Diagram-section (after Prestwich) showing how a spring may rise beneath water. A, fissured rocks allowing water to percolate into the channels *c*, *c*, *c*. *p*, point where the channels come to the surface of the rock beneath the water. *s*, spring rising through water.

242. **Submarine Springs**.—It is not difficult to see how in certain circumstances a spring of water may occur in the bed of a river, or even beneath the surface of the sea. Submarine springs of fresh water are found on several parts of the Mediterranean coast. Where the coast is high, and the rocks are fissured in such a way that the orifice of escape is beneath the sea, the pressure of the water at the higher levels may be so great as to drive out the fresh water into the sea-bed. Owing to its lighter specific gravity, as well as to the force of ejection, the water of such a spring rises to the surface (see fig. 106).

243. **Intermittent Springs.**—Some springs are met with whose flow is discontinued for a time and then begins again. These intervals are of various duration, and seem to depend chiefly on the amount of rain. The phenomenon is easily understood on reference to fig. 107. Here we see a subterranean cavity, which may have arisen either by the solvent action of the water or in consequence of some violent disturbance. It is fed by a number of fissures in the overlying rock, and the channel of escape is seen to curve upwards. As long as this underground reservoir is filled to the height of the bend by which the water escapes, the spring seen at the foot of the rock continues to flow; but when a time of drought comes the water in the reservoir is drained off by siphon action, and the flow ceases.

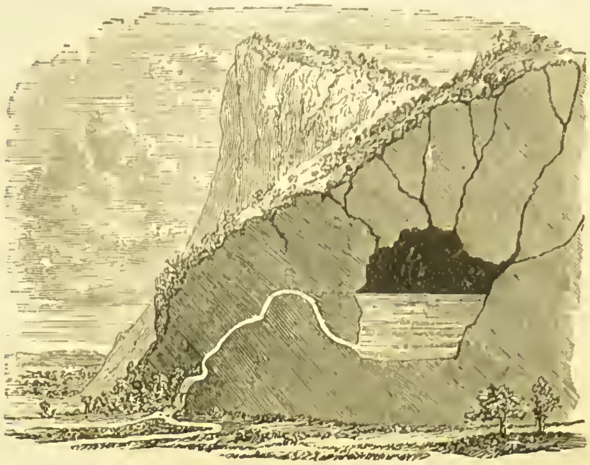

FIG. 107.—Intermittent Spring.

244. **Landslips.**—It occasionally happens that large masses of rock slide down a hill or mountain into a valley, or on to a sea-coast. In such cases the strata are usually inclined towards the direction of the falling mass. This slips down because the action of the underground water has removed or rendered soft and slippery the supporting stratum, and hence the overlying portion slides forward and tumbles down. Such calamities often happen after a rainy season in mountainous districts where porous beds, such as sandstone or conglomerate, rest on sloping beds of impervious clay. The great fall from the Rossberg mountain in Switzerland on September 2, 1806, was brought about owing to the support of some upper beds being removed after a long period of rain. An immense mass of rock slipped down into the plain of Goldau, destroyed two villages, and killed 800 persons. A large landslip took place at Axmouth, on the Dorsetshire coast, in 1839. This was caused by the springs that issue from the face of the cliffs gradually removing the support of the upper part of the cliffs, so that the superincumbent mass fell forward towards the sea.

245. **Geysers.**—Geysers are hot springs which are chiefly found in volcanic districts, and which shoot up columns of water at various intervals. These intermittent jets sometimes rise to a height of two hundred feet. The Yellowstone Park in the Rocky Mountains is the most remarkable geyser region in the world. The great Beehive Geyser discharges a column once a day, while others play almost every hour. Iceland is another well-known geyser region. All the geyser waters hold in solution a considerable quantity of silica. The highly heated water decomposes the felspar and other volcanic rocks, and becoming slightly alkaline with the soda or potash these contain, it is enabled to form a silicious solution. The silica taken up is deposited again round the mouth of the orifice. Minute plants termed algæ are known to live in the hot water, and to aid in throwing down the silica from solution to form the sinter deposits (par. 135).

The cause of the periodical eruptions is probably to be found in the gradual increase of heat with the depth of the tube. In the middle and lower parts the temperature is far above the boiling-point (212° F.) at the ordinary pressure. But at last the lower portion rises to a position where the temperature is above the boiling-point at the pressure it there sustains, and then, flashing into steam, it hurls the column above into the air. After playing for a few minutes the water falls back into the basin, and remains quiet for a time.

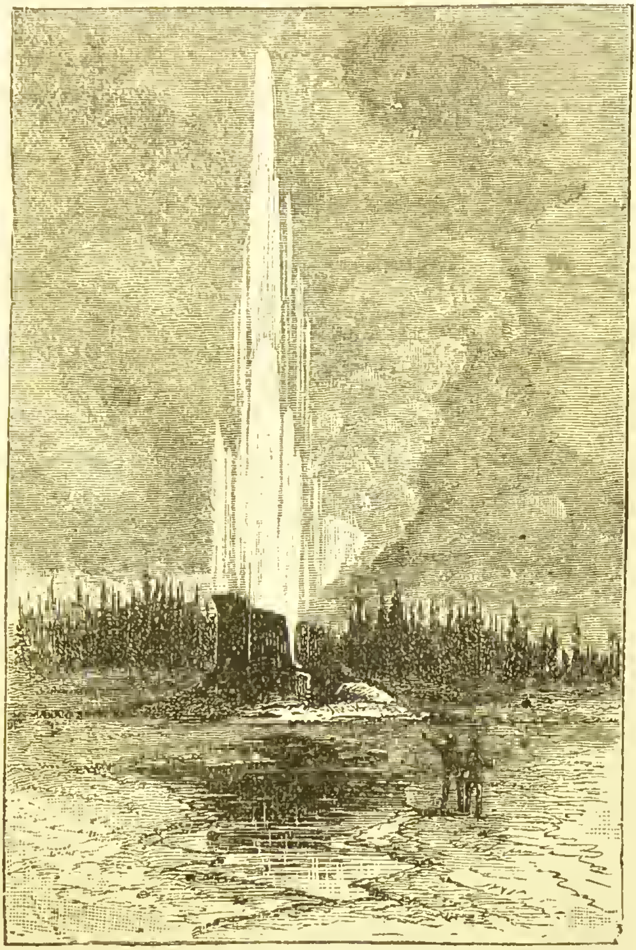

FIG. 108.—The Giant Geyser, United States.

246. **Glaciers.**—The snow which falls above the snow-line partly disappears through evaporation from its surface, but as the supply far exceeds the waste, it tends to accumulate. On attaining a certain depth its own weight is sufficient to press the lower portions into ice, and this change into ice is also brought about by the water that forms during the heat of midday sinking through the crevices of the mass and freezing at night. Successive layers are formed as each winter's snowfall succeeds another, and a semi-compact granular mass of ice forms at the upper cup-shaped end of a mountain valley. The beds of snow accumulated by each winter's fall form layers of irregular thickness, being usually separated by a dirt-line, consisting of dust and

fine grit that has been blown on to the surface in summer. When a sufficient depth of such snow-derived ice has collected, the lower portions are squeezed out and, impelled by gravity and the pressure behind, travel down the valley slope as a *river of ice*, or *glacier*. This compacted parent mass of snow-ice is called *névé*, or *firn*, and it only gathers where there is a suitable cup-shaped expansion at the head of a mountain valley that reaches up to the snow-fields. On conical mountains with very steep sides the snow does not gather, but soon falls down to the foot, where it is melted. Hence a glacier may be described as a stream of ice formed by the consolidation through pressure of mountain snow. From the sides of steep mountains masses of snow sometimes slide down suddenly, and, accumulating as

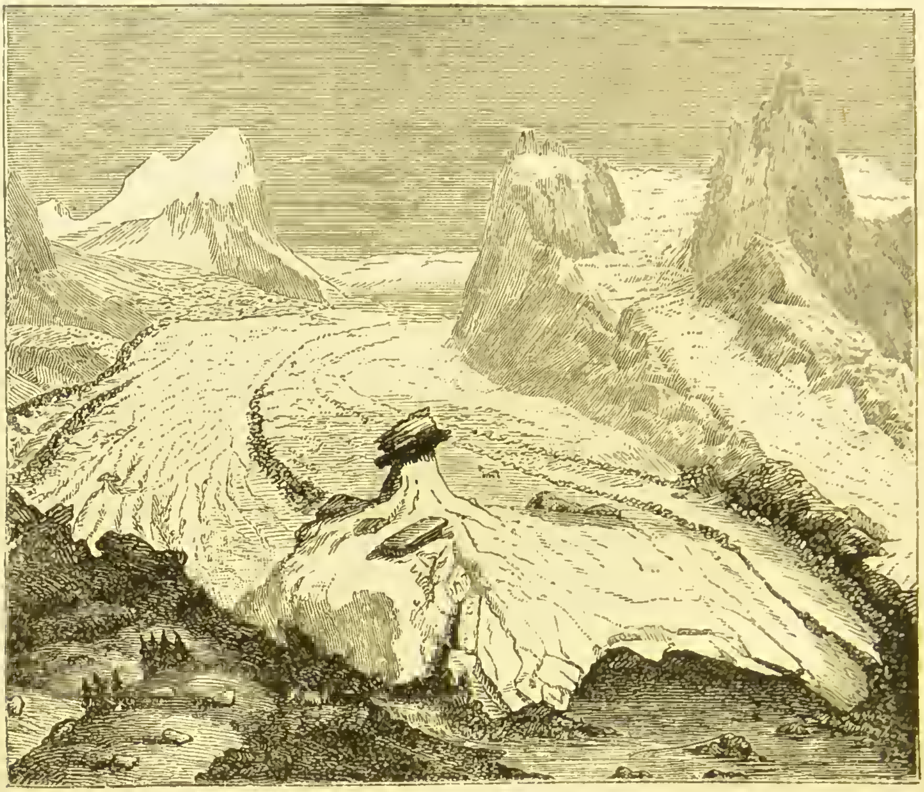

FIG. 109.—Glacier Landscape, showing the origin in distant snow-fields and the river flowing out from the archway of ice at the end. On the surface are seen great fissures (crevasses), lines of rubbish (moraines), and a pillar of ice capped by a block of stone (glacier table). In the foreground are shown ice-worn hummocks of rock (*roches moutonnées*) and transported blocks of stone.

they descend, cause great destruction in the valleys below. Such falling masses are called *avalanches*.

247. **Motion and Size of Glaciers.**—A glacier fills up its valley to a certain height, and accommodates itself to the various windings. It moves slowly down, being pushed on from above, partly by sliding and partly by a yielding in the mass itself. Professor Tyndall attributes this yielding to continual fracture and regelation in the mass, but Forbes maintained that ice behaves like a very viscous fluid, the glacier being a plastic mass with tenacity sufficient to mould itself upon the obstacles which it encounters, except where the forces are so violent as to produce fissures. As mountain valleys often lead into one another, several glaciers may unite in a single valley to form one large trunk glacier. The rate at which a glacier moves varies with the season and slope, the motion being less in winter than in summer. The motion, too, is greater at the centre than at the side, greater in its upper than in its lower surface. In this respect it exactly resembles the flow of a river. The motion has been *proved* by driving a straight row of stakes across a glacier, and observing these in the following year. They were all found to have moved down, but those nearest the middle had moved farthest, and the stakes thus presented the form of a curve. Some glaciers, where the slope is slight, move only three or four inches a day; in other cases a rate of from three to four feet a day has been observed. Greenland glaciers have a still greater rate of motion (par. 193). The varying rate of the motion of the ice in different parts of the glacier and the irregularities of its bed, cause strains in the ice, by which

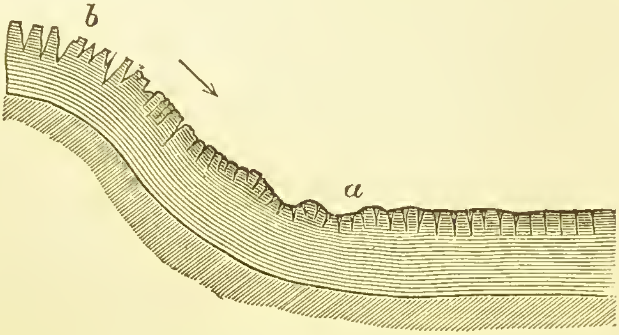

Fig. 110.—Longitudinal Section of a Glacier, showing large crevasses at *b* on the steep slope.

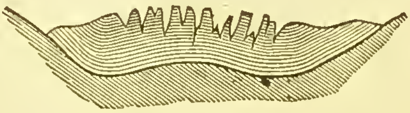

Fig. 111.—Cross-section of a Glacier.

fissures or *crevasses* are produced. Some of these crevasses are of immense size, especially where there is a sudden descent in the bed of the glacier, and the ice falls over the summit of a slope. Hence the surface of a glacier is seldom even, but has the appearance of broken and irregular blocks confusedly heaped together. The Swiss Glacier varies in length from 5 to 16 miles, in breath from ¼ to 3 miles, and in depth from 500 to 1,000 feet. The huge Baltoro Glacier, fed by the névé of the Korakoram Mountain, is 36 miles long. But even this is exceeded by the Arctic glaciers which cover Greenland, and which give origin to icebergs as already explained. The Norwegian glaciers are mostly shorter than the larger Swiss glaciers. As the glacier is pushed down the valley it is constantly being lessened by evaporation and liquefaction, but the pressure of the mass behind usually causes the compact ice to descend below the snow-line, sometimes to a distance of 5,000 feet. It ends as a broken cliff of ice, with an archway from which flows a stream of muddy water. During periods when the snowfall on the height is less than usual, or when the summer heat is unusually great, the foot of the glacier retreats. Most of the Swiss glaciers are thus falling back somewhat, and this seems to point to some change of climate.

248. **Moraines.**—The sides of the steep rocky valleys through which the glacier descends are constantly being acted upon by the weather, and angular fragments of rock frequently fall on the sides of the glaciers. These form what are called the *lateral* or *side moraines.*

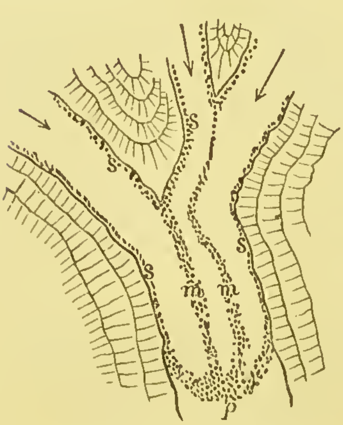

FIG. 112.—Plan showing Position of Moraines. *s*, *s*, lateral moraines; *m*, *m*, middle moraines; *p*, terminal moraines.

When two glaciers unite to form one stream, two of the lateral moraines unite and descend along the centre, forming what is called a *medial* or *central moraine* (see fig. 112). Both the lateral and medial moraines are transported along the surface of the glacier to where it terminates, and there the mass of stones and rubbish is discharged, forming in front of the glacier what is called a *terminal moraine.* In this way hundreds of tons of rocks, some of which have been borne on the back of the glacier for many miles, are gathered together. The surface of the glacier is constantly decreasing by evaporation and the sun's heat, and thus in summer streams of water pour into the crevasses, and flow along beneath the surface till they reach the foot. In some parts a block of stone prevents the melting of the ice beneath it, so that there a column of ice forms having a stone cap. This is known as a *glacier table.*

249. **Erosion of Rocks by Glaciers.**—Not only does the glacier carry down numerous rock-masses on its surface, but others, called the *moraine profonde*, are pushed along beneath the glacier, finally forming part of the terminal moraine. Many of these have fallen from the surface into crevasses at the sides or in the middle of the glacier. On emerging at the end they show an appearance very different from the angular fragments that are deposited from the lateral and medial moraines. While beneath the surface and held in by ice they have been subjected to great friction on the bottom or sides of the rocky glacier-bed. All their corners and projections are worn off, and their surfaces have a smooth and polished appearance. They have been ground against the underlying rocks, and have in their turn grooved and scratched the rocks over which they have passed, the marks of this scratching being known as *striæ* (fig. 119). In this polishing and marking of the rocks the fine sand and silt resulting from the wear acts like emery powder in polishing the exposed surfaces. On the bed of the glacier are found smooth rounded rocks, known from their appearance as *roches moutonnées* (sheep-rocks). The dome-shaped *roches moutonnées* have usually a smooth and rough side, the smooth slope being in the direction from which the ice travels; while other *roches moutonnées* are rounded, striated, and polished on all sides. Such *roches moutonnées* are to be seen when the foot of a glacier retreats during a hot season, or they may be found exposed on what was once the bed of an ancient glacier.

In the bed of a glacier, hollow rounded cavities called *moulins*, or *glacier-mills*, are drilled out where a stream of water, derived from the melted ice of the upper surface, descends through a crevasse. Such little rivulets frequently form and fall down with a loud roar. As the supply of water is cut off by a fresh crack a new moulin is formed. Some of these streams scoop out in the solid rock a moulin many feet deep.

250. **Glacier Waters.**—The turbid water issuing from the cavity at the foot of a glacier has been partly derived from the melting that has taken place all along the surface, partly from the melting at the bottom of the bed due to friction, and partly, it may be, from springs. It has always a peculiar milky appearance, due to the light grey sediment in suspension. The impalpable powder that forms this sediment is one of the

products of the enormous grinding that goes on underneath the ice mass, and its fineness keeps it from falling down until the river has reached the lower and quieter part of its course. Some of the sediment of the Rhine Glacier may be found deposited on the flats of Holland. When deposited this silt forms a kind of bluish-grey loam or clay. Rivers which take their rise in glaciers are always fuller and more turbulent towards the end of summer than at other times, as then the greatest amount of ice is melted. In winter the flow from the foot of the glacier is at its minimum.

251. Ancient Glaciers.—As the rocks over which glaciers pass are so distinctly marked, and as the transported material is so great, it is plain that any old glaciers that have disappeared will have left marks and relics that may be easily recognised. Polished rocks and moraines of former glaciers can be seen in many parts of the lower Swiss valleys, and in several countries of Europe, Asia, and America, where no glaciers are now found. Moraine matter, striated and planed rocks, may even be found in the valleys of Snowdon and Cumberland, and the morainic matter from old British glaciers is scattered over many parts of our country, and is known as Boulder Clay. Long before history begins the valleys of Britain were filled with glaciers, thus showing that the climate of our country was once very different. Rounded sheep-rocks (*roches moutonnées*) may be easily found in the Lake district and various parts of Scotland. The former enormous extent of glaciers is also proved by the numerous transported blocks. Their huge size, their angular corners, and their difference from the rocks on which they are found, all afford evidence that they have been carried into their present position by ice. These detached masses were left by the ice on the surface of other rocks, often on the summit or edges, and are known

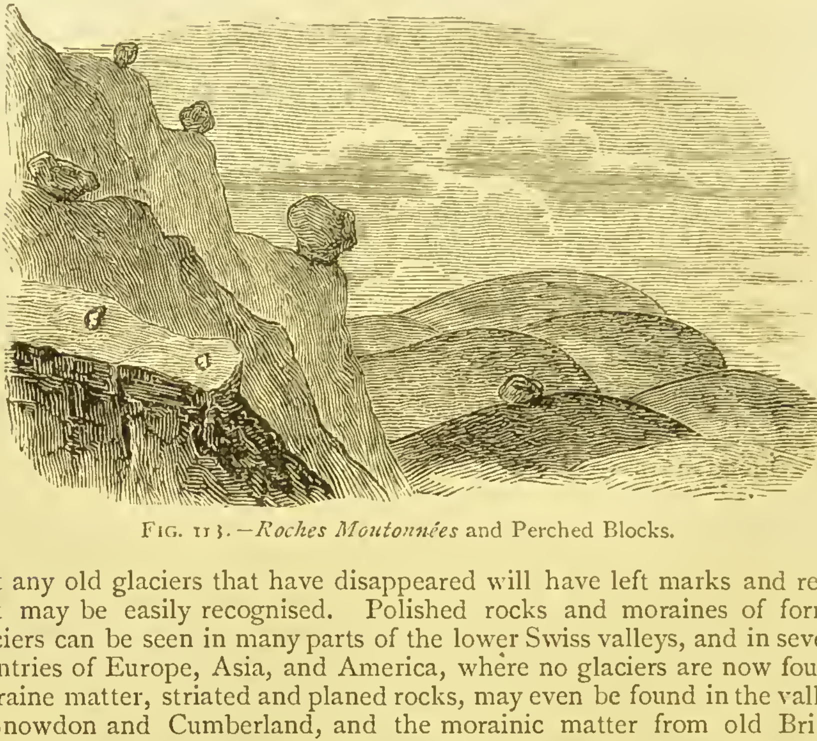

FIG. 113.—*Roches Moutonnées* and Perched Blocks.

as *perched blocks*. They are well seen in the Pass of Llanberis, on the sides of Snowdon. (The word *boulder* is generally restricted to large water-worn rounded masses of stone, or to the more or less ice-worn blocks found in the stony clay called Boulder Clay.)

252. **Glacières.**—This word must not be confounded with glaciers. Glacières are ice-caverns, or caves full of ice. They occur unconnected with any glaciers, and are found in certain districts where a cold current of air enters a hollow cavity, and where ice is formed in winter which is not melted by the warmth of summer, though the temperature of the cave may then be above freezing-point. A remarkable glacière is found at Dobschau, in Hungary; others are found in various parts of the Alps, and in Iceland.

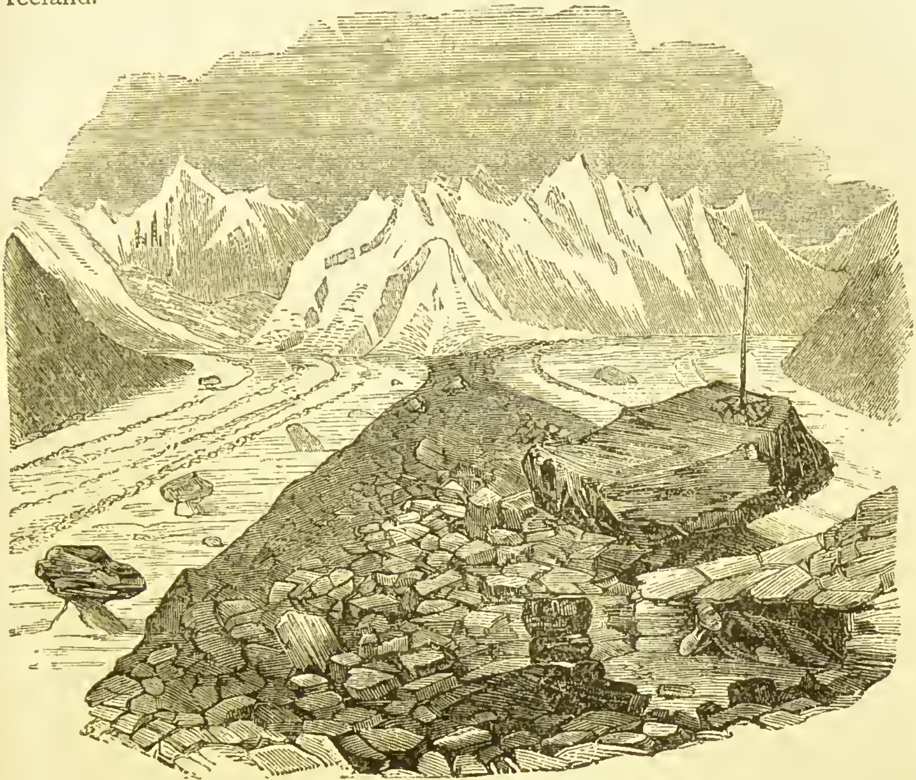

FIG. 114.—View from Central Moraine of a Glacier.

253. The following passages from an eloquent lecture on glaciers by Professor Helmholtz [1] will assist in giving the reader more vivid and distinct ideas regarding these wonderful phenomena:—

'The outward appearance of glaciers is very characteristically described by comparing them, with Goethe, to currents of ice. They generally stretch from the snow-fields along the depth of the valleys, filling them throughout their entire breadth, and often to a considerable height. They thus follow all the curvatures, windings, contractions, and enlargements of the valley. Two glaciers frequently meet, the valleys of which unite. The two glacial currents then join in one common principal current, filling up the valley common to them both. In some places these ice-currents present a tolerably level and coherent surface, but they are usually traversed by *crevasses*, and both over the surface and through the crevasses countless small and large water-rills ripple, which carry off the water formed by the melting of the ice. United and forming a stream, they burst, through a vaulted and clear blue gateway of ice, out at the lower end of the larger glacier.

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[1] Translated by Professor Atkinson.

'On the surface of the ice there is a large quantity of blocks of stone, and of rocky *débris*, which at the lower end of the glacier are heaped up and form immense walls; these are called the *lateral* and *terminal moraine* of the glacier. Other heaps of rock, the *central moraine*, stretch along the surface of the glacier in the direction of its length, forming long regular dark lines. These always start from the places where two glacial streams coincide and unite. The central moraines are in such places to be regarded as the continuations of the united lateral moraines of the two glaciers.

'The formation of the central moraine is well represented in the view above given of the Unteraar Glacier (fig. 114). In the background are seen the two glacier currents emerging from different valleys—on the right from the Schreckhorn, and on the left from the Finsteraarhorn. From the place where they unite the rocky wall occupying the middle of the picture descends, constituting the central moraine. On the left are seen individual large masses of rock resting on pillars of ice, which are known as glacier tables.

'To exemplify these circumstances still further, I lay before you in fig. 115 a map of the *Mer de Glace* of Chamouni, copied from that of Forbes.

'The Mer de Glace in size is well known as the largest glacier in Switzerland, although in length it is exceeded by the Aletsch Glacier. It is formed from the snow-fields that cover the heights directly north of Mont Blanc, several of which, as the Grande Jorasse, the Aiguille Verte (a, fig. 115), the Aiguille du Géant (b), Aiguille du Midi (c), and the Aiguille du Dru (d), are only 2,000 to 3,000 feet below that king of the European mountains. The snow-fields which lie on the slopes and in the basins between these mountains collect in three principal currents, the Glacier du Géant, Glacier de Léchaud, and Glacier du Talèfre, which, ultimately united as represented in the map, form the Mer de Glace; this stretches as an ice-current 2,600 to 3,000 feet in breadth down into the valley of Chamouni, where a powerful stream, the Arveyron, bursts from its lower end at k, and plunges into the Arve. The lowest precipice of the Mer de Glace, which is visible from the valley of Chamouni, and forms a large cascade of ice, is commonly called Glacier des Bois, from a small village which lies below.

'Most of the visitors at Chamouni only set foot on the lowest part of the Mer de Glace from the inn at the Montanvert, and when they are free from giddiness cross the glacier at this place to the little house on the opposite side, the Chapeau (n). Although, as the map shows, only a comparatively very small portion of the glacier is thus seen and crossed, this way shows sufficiently the magnificent scenes, and also the difficulties of a glacier excursion. Bolder wanderers march upwards along the glacier to the Jardin, a rocky cliff clothed with some vegetation, which divides the glacial current of the Glacier du Talèfre into two branches; and bolder still they ascend yet higher, to the Col du Géant (11,000 feet above the sea), and down the Italian side to the valley of Aosta.

'The surface of most glaciers is dirty, from the numerous pebbles and sand which lie upon it, and which are heaped together the more the ice under them and among them melts away. The ice of the surface has been partially destroyed and rendered crumbly.

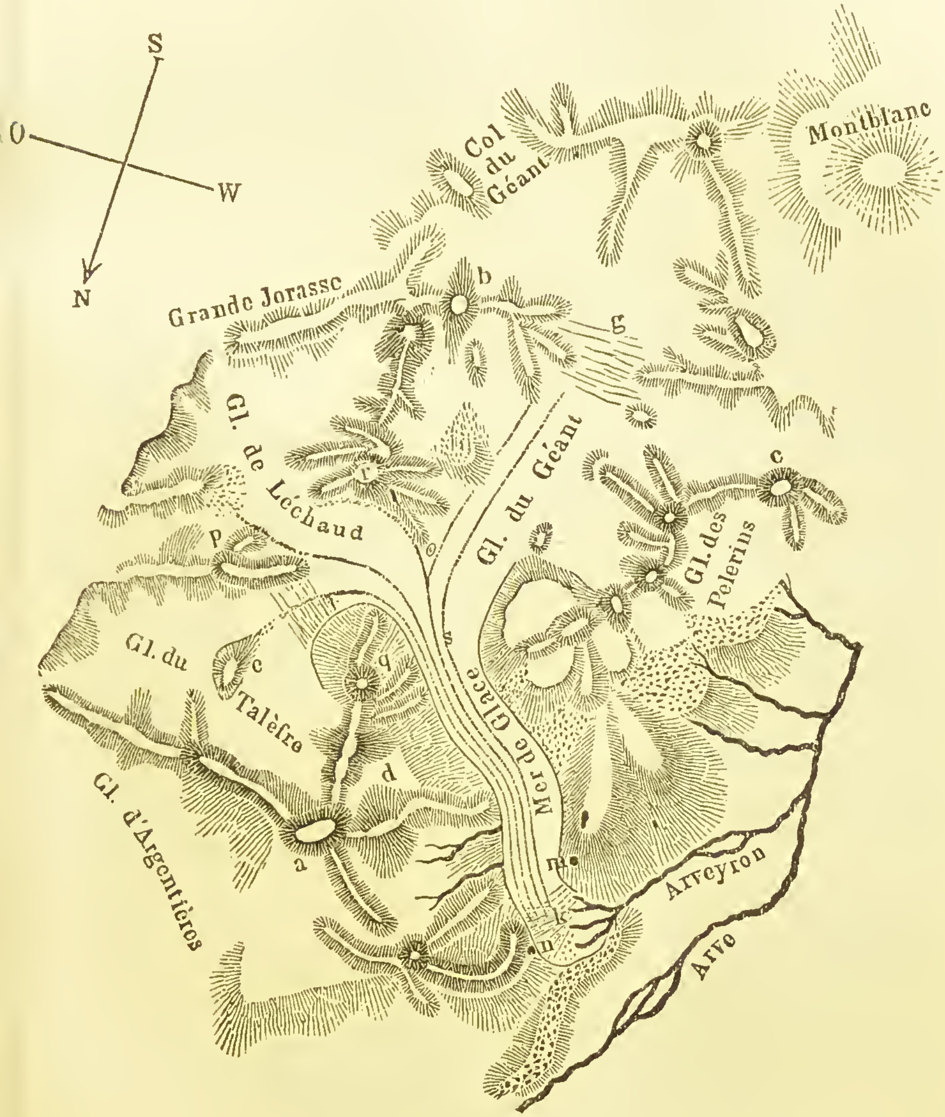

FIG. 115.

'In the depths of the crevasses ice is seen of a purity and clearness with which nothing that we are acquainted with on the plains can be compared. From its purity it shows a splendid blue, like that of the sky, only with a greenish hue. Crevasses in which pure ice is visible in the interior occur of all sizes: in the beginning they form slight cracks in which a knife can scarcely be inserted; becoming gradually enlarged to chasms, hundreds or even thousands of feet in length, and twenty, fifty, and as much as a hundred feet in breadth, while some of them are immeasurably deep. Their vertical dark blue walls of crystal ice, glistening with moisture from the trickling water, form one of the most splendid spectacles which nature can present to us; but, at the same time, a spectacle strongly impregnated with the excitement of danger, and only enjoyable by the traveller who feels perfectly free from the slightest tendency to giddiness. The tourist must know how, with the aid of well-nailed shoes and a pointed alpenstock, to stand even on slippery ice, and at the edge of a vertical precipice the foot of which is lost in the darkness of night, and at an unknown depth.

'We have hitherto compared the glacier with a current as regards its outer form and appearance. This similarity, however, is not merely an external one; the ice of the glacier does, indeed, move forwards like the water of a stream, only more slowly. That this must be the case follows from the considerations by which I have endeavoured to explain the origin of a glacier. For as the ice is being constantly diminished at the lower end by melting, it would entirely disappear if fresh ice did not continually press forward from above, which, again, is made up by the snowfalls on the mountain tops.

'But by careful ocular observation we may convince ourselves that the glacier does actually move. For the inhabitants of the valleys—who have the glaciers constantly before their eyes, often cross them, and in so doing make use of the larger blocks of stone as sign-posts—detect this motion by the fact that their guide-posts gradually descend in the course of each year. And as the yearly displacement of the lower half of the Mer de Glace at Chamouni amounts to no less than from 400 to 600 feet, you can readily conceive that such displacements must ultimately be observed, notwithstanding the slow rate at which they take place, and in spite of the chaotic confusion of crevasses and rocks which the glacier exhibits.'

254. General Results of Denudation.—The general tendency of the various denuding agents is to crumble away rocks and to carry the débris from higher to lower levels. In this way lakes are filled up and disappear, the sea bottom is covered with layers of sediment, and material is thus accumulated that will afterwards be consolidated into rocks. But in doing so the various denuding agents act unequally. In one place the land is eroded or eaten away at a comparatively great rate; in another place some of the denuding agents are absent, or their power is checked by the hardness of the rock, and little waste goes on. Various inequalities of outline are thus produced on the surface of the earth. Table-lands are carved out into valleys and hills, ravines are deepened and widened, and mountains are rendered more rugged and precipitous. Some idea of the tremendous amount of waste and the vast periods of time may be formed when it is pointed out that nearly the whole of the present scenery of Scotland, its moun-

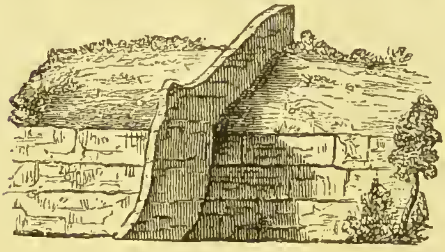

FIG. 116.—Dyke of Igneous Rock laid Bare by Denudation.

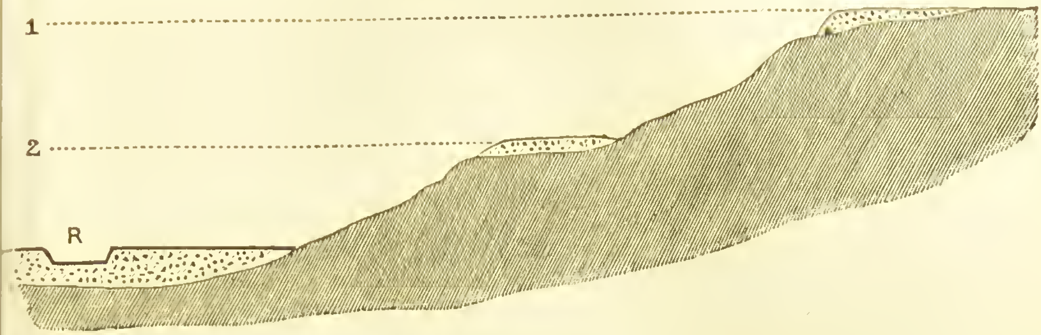

Fig. 117.—River Terraces. 1, 2, levels at which the river was flowing when the upper and second terraces were formed respectively. R, The present position of the river. The dotted portions represent material brought by the river.

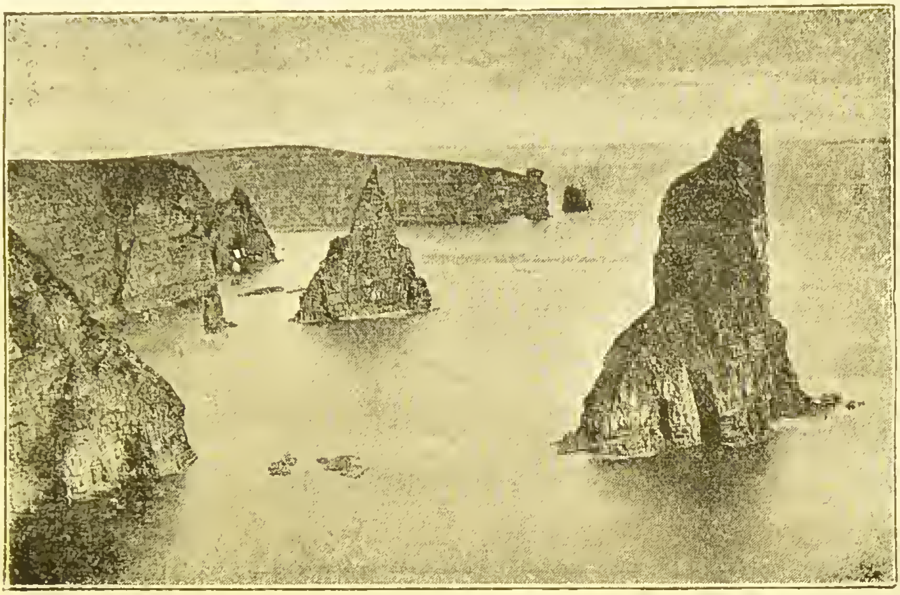

Fig. 118.—The Stacks of Duncansby. Evidence of waste of coast. (Wilson.)

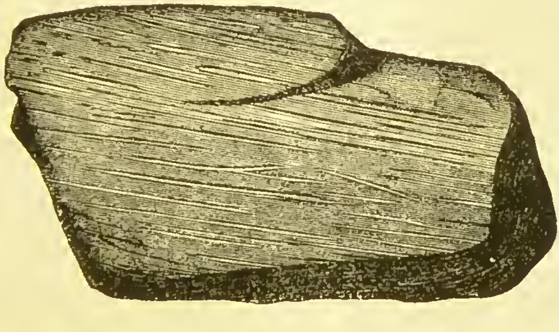

Fig. 119.—Striated Block, or scratched stone from a Glacial deposit.

tains and glens, its uplands and lowlands, are mainly the result of the denuding tools that have sculptured its present surface. The level of the basin of the Ganges is being lowered at the rate of one foot in 2,400 years, while in the case of the Po the rate is one foot in 730 years. Professor Geikie calculates that the rate of denudation in the British Isles is one inch in 800 years, and that it would require 5,500,000 years before the land was reduced to the level of the sea. But while this crumbling of the rocks and dispersion and deposition of the material removed have been going on, other changes have been occurring which tend to counteract the levelling produced by denudation. For though the land is slowly sinking in some areas, upheaval is taking place over large tracts; and volcanic activity, at one time much greater than now, frequently throws up immense quantities of matter in floods of lava or showers of ashes. There is thus a constant struggle between the two opposing forces, denudation and upheaval.

255. **Representation of the Surface of the Earth on Maps.**—For a considerable period officials of our Government have been engaged in making a National Survey of the United Kingdom, and the results of their labours are embodied from time to time in reports and maps. These maps are on various scales.[1] The General Map of the kingdom is published in sheets, and is on the scale of one inch to the mile; that is, it is $\frac{1}{63360}$ of the natural scale, there being 63,360 inches in a mile: in other words, one inch in length represents a distance of one mile, and one square inch represents one square mile. The county maps, which may also be obtained in suitable sheets, are on the scale of six inches to the mile, or $\frac{1}{10560}$ of the natural scale. Parish maps and plans of towns are on a still larger scale. Besides showing the rivers, canals, railways, bridges, turnpike roads, &c., most of these maps show *relief*, that is, the undulations or surface elevations of the country, either by means of *contour lines* or by *hachures*. *A contour line is a line passing through all places which are at the same height above the sea level.* The sea margin at a certain state of tide is taken as the datum level, and may be regarded as the contour line of no elevation. Imagine a mountainous island, and suppose the water to rise a certain height, say 50 feet. A new water level would be formed 'encroaching more on the land than the former; encroaching most at places where the beach has the gentlest slope, not encroaching at all on a perpendicular cliff,

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[1] A catalogue of the various maps and plans published by the Ordnance Survey may be obtained through a bookseller.

and thrust out (seawards) from an overhanging cliff.' We should thus obtain a new contour line of 50 feet elevation. By supposing a gradual rise of the sea we should obtain a series of curved contour lines which would finally close in over the highest peak. The engineers of the survey obtain their levels for these *contours*, or 'lines of equal altitude,' by means of surveying, and do not require the imaginary floods which we have supposed. Contour lines may be drawn at any intervals, but those generally chosen are intervals of 50 or 100 feet of additional elevation above the sea level. Lieut.-Colonel T. P. White, R.E., the executive officer of the survey, states in his little book entitled 'The Ordnance Survey of the United Kingdom,'[1]—

> 'These contours are given on our one-inch map to the highest altitudes, and, excepting for some of the uncultivated and mountainous tracts of Scotland, also on the six-inch maps, up to 1,000 feet, but not (save in a very few special cases) on any of the other scales. The procedure of the survey has, however, varied in this matter. In Lancashire the contours were shown on the six-inch map as close as 25 feet (vertical) apart, both in the high and low ground, and at the same interval in Yorkshire, up to the limit of 1,200 feet: above that limit the Yorkshire contours were given at every 50 feet of elevation. The contours are of the greatest value to engineers and others for laying out railways, roads, canals, water-leads, drainage, &c., and for constructing ground-sections to illustrate a particular line of country. "They also form an admirable basis for hill-sketching, and for correctly expressing to the eye the surface of a country."'

Where the ground has a gentle slope the contours spread out, and where it is steep they come close together. The shortest line drawn to the nearest contour line will give the line of steepest slope, or the *stream-line*, as it is called; and the *gradient*, or amount of rise in a horizontal foot, is inversely as the distance in that direction between successive contour lines. Knowing their distance apart we can easily tell by means of these contours the height of any particular part above or below another, and can also picture to ourselves the slope of the ground. Figures are often attached to the dotted contour lines on the maps of the Ordnance survey. If we had a hill shaped like a right cone, there would be uniform steepness throughout, and the concentric circles representing the contour lines would be at equal distances. In a hemispherical hill the lines would be close together at the boundary of the hill, and would spread out greatly near the top. The reader may make the water-level experiment with a good-sized round orange, half of which may be placed in a flat-bottomed dish, and water poured in to successive equal vertical heights. The annexed figure shows the contour lines round a hill at successive intervals of 100 feet. The hill, however, can only be shown in section, but the inequalities of slope on the sides not seen may be judged of from the shape of the different contours.

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[1] Blackwood and Sons, 1886.

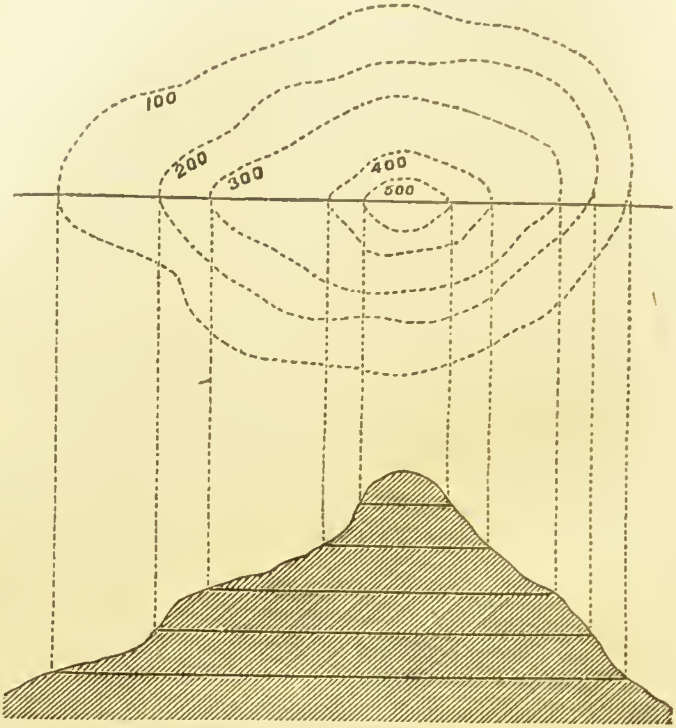
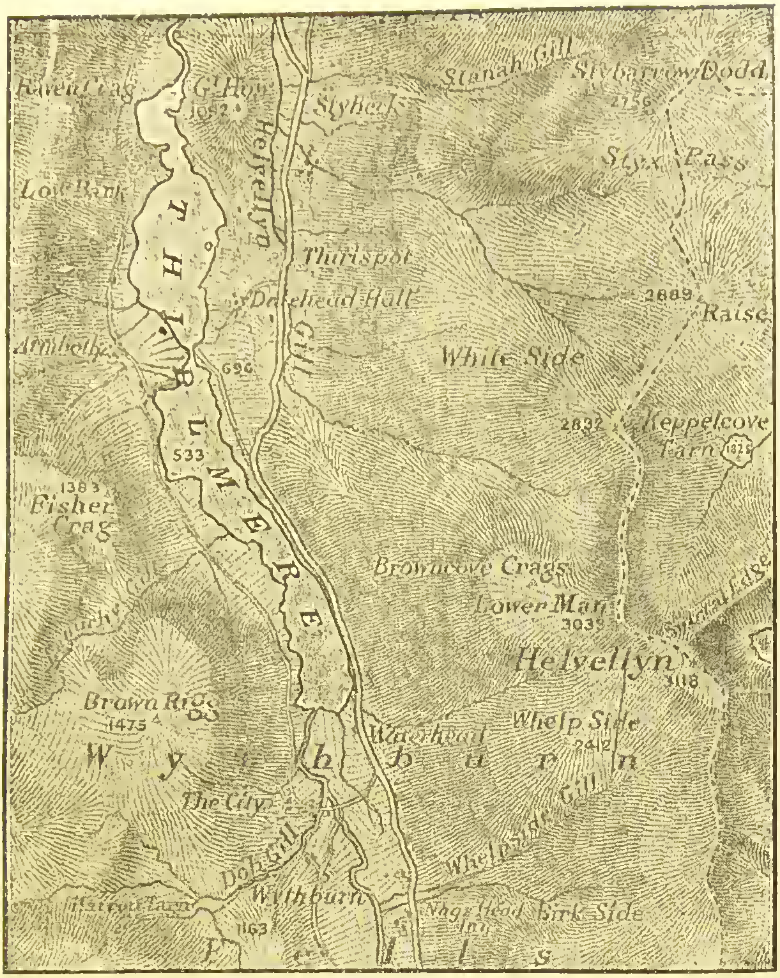


Fig. 120.—Contour Lines round a Hill.

The other method employed to represent the surface of the ground is by what are termed *hachures.* Hachures are shading lines, and these lines are made thicker and closer the steeper the ground is. This shading of the hill-features on the one-inch maps is executed on the principle—

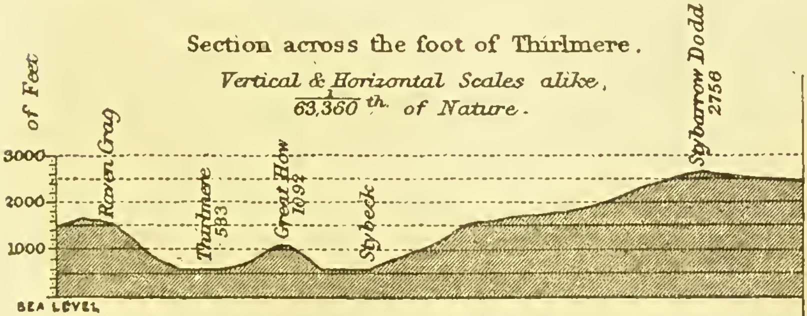
> 'that the eye, in looking at the map, should be drawn at once to the highest summits by the emphasising of the shading there, and be able to distinguish the intermediate heights down to the lowest ground by the relative strength of the shade. Another mode of showing the relief of a district is by giving ideal *sections* across various parts. The map annexed shows the contour lines and hachures of a part of the Thirlmere Valley, in Westmoreland, and two sections of the valley are added.



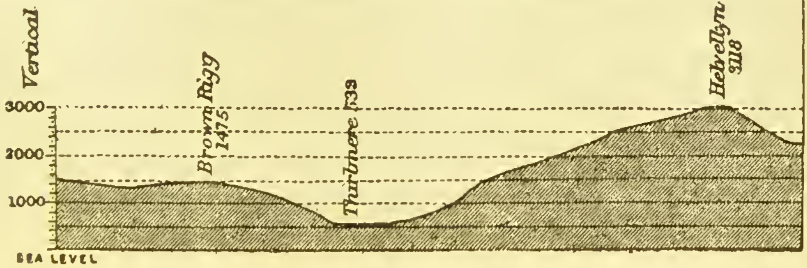
Map IX.—Map of Thirlmere Valley, showing Contours and Hachures.

Section across the foot of Thirlmere.

Vertical & Horizontal Scales alike, $\frac{1}{63,360}$th of Nature.



Section across the head of Thirlmere.



CHAPTER XIII.

WEATHER AND CLIMATE.

256. **Weather and Weather Charts.**—The weather at any particular place may be described as the combination of all the atmospheric phenomena existing at one time. It therefore includes the temperature, barometric pressure, wind, moisture, cloud, and electricity of the atmosphere; and a change of weather implies a change in one or more of these elements. Various kinds of *weather charts* are now published in the newspapers, and by a careful study of these it is often possible to make a forecast of the weather for a day or two in advance. Since, as we have seen, changes in the pressure of the atmosphere are indications of changes in the wind, and since the prevailing winds act as carriers of moisture and temperature, barometric readings are of the greatest importance. The 'Times' daily weather chart is a map of North-western Europe on which are marked the *isobars* at differences of $\frac{1}{10}$ of an inch. The temperature, the direction and strength of the wind, the state of the sky as to cloud, and the state of the sea are also indicated. The reader should obtain one of these charts and carefully study it.

'If we take a horizontal line between two isobars, and at that point at which the pressure is greatest draw a perpendicular line on any suitable scale, which shall represent the difference in pressure between the two places, the line drawn from the top of this perpendicular to the lower isobar will form an angle with the horizontal, and the steepness of this angle is the measure of the fall in pressure between the two stations, and is called the *barometric gradient.*'

Gradients are expressed in hundredths of an inch of mercury for distances of one degree, or sixty nautical miles, and the closer the isobars are together the steeper is the gradient, and, as a rule, the stronger the wind. The direction of the wind, as before pointed out, is from the district of high pressure to that of lower pressure. To this general statement Buys Ballot of Utrecht has added the following law for the Northern Hemisphere: *Stand with your back to the wind, and the line of lower pressure is on your left hand.* The opposite of this is true of the Southern Hemisphere. The meteorological reports of other papers take different forms, all of which are instructive. The 'Graphic' supplies every week a diagram on which the pressure and the temperature for the previous week are indicated on a special chart. Here is an example of its weekly weather chart, and the pupil may probably be induced to construct a similar one for himself from day to day. The explanations already given when speaking of the atmosphere will, with those supplied by the paper, be sufficient.

WEATHER CHART

For the Week ending Wednesday, September 7, 1887.

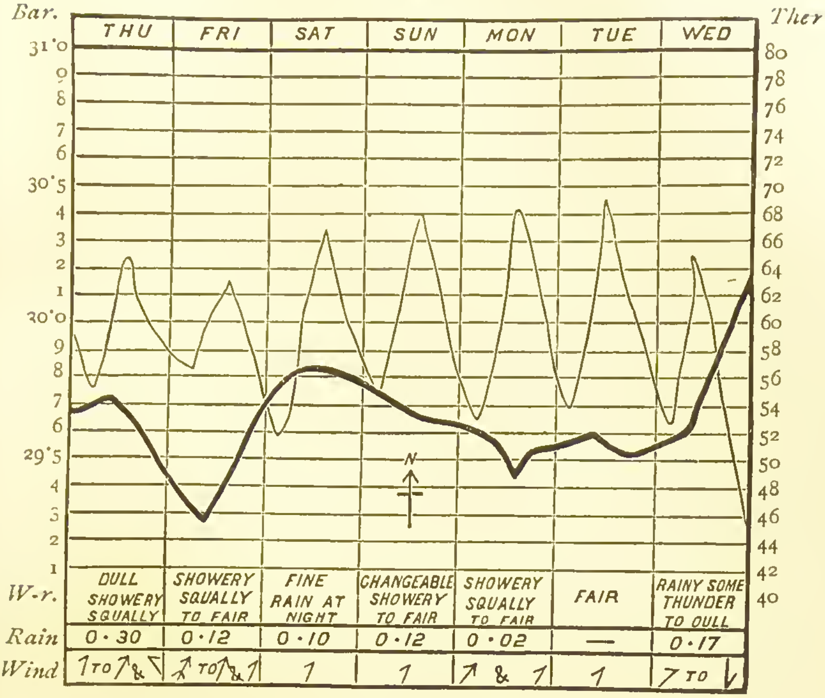


FIG. 121.

EXPLANATION.—The thick line shows the variations in the height of the barometer during the week ending Wednesday midnight (7th inst.). The fine line shows the shade temperature for the same interval, and gives the maximum and minimum readings for each day, with the (approximate) time at which they occurred. The information is furnished to us by the Meteorological Office.

REMARKS.—The weather of the past week has been exceedingly unsettled. Rain has fallen every day, temperature has been somewhat low for the time of year, and high winds have prevailed very generally over the southern parts of the United Kingdom. At the beginning of the period the centre of a deep depression passed in a north-easterly direction over our islands, causing considerable falls of rain in all districts, and severe south-westerly to westerly gales in the south of England. It will be seen from the diagram that the lowest point was reached by the barometer in London at about 8 A.M. on Friday (2nd inst.), after which the mercury rose briskly. In the rear of the depression the wind moderated, and the weather improved temporarily, but on Saturday evening (3rd inst.) another shallow disturbance appeared over our western coasts, and showers were again experienced generally, with strong south-westerly winds in the south. On Monday (5th inst.) yet another system of considerable depth advanced over our western districts, and the wind rose to the force of a moderate gale over the greater part of Ireland and England. On reaching Scotland the last-mentioned disturbance became shallower, and on Tuesday night (6th inst.) it passed eastwards over England to the North Sea. In its rear a rapid rise of the barometer took place generally, and at the close of the week the wind had veered to the northward in all districts, with a considerable fall of temperature.

The barometer was highest (30·13 inches) on Wednesday (7th inst.); lowest (29·29 inches) on Friday (2nd inst.); range 0·84 inch.

The temperature was highest (69°) on Tuesday (6th inst.); lowest (52°) on Saturday (3rd inst.); range 17°.

Rain fell on six days. Total amount 0·89 inch. Greatest fall on any one day 0·30 inch on Thursday (1st inst.).

Instead of a chart the 'Standard' newspaper publishes a tabular statement, of which the following is an example. It is for the week ending October 31, 1887, and the readings are those taken in London. The various instruments which give these results have been explained in former paragraphs.

METEOROLOGICAL READINGS

(*Taken Daily at* 7.0 P.M. *by Stewart's Instruments*).

'THE STANDARD' OFFICE, November 1.

Date	Barometer reduced to Sea Level and 32° F.	Direction of Wind	Dry Bulb	Wet Bulb	During the past 24 hours			
					Max. Solar Radia. in Vac.	Max. Shade Temp.	Min. Temp.	Rainfall
Oct. 25	30·59	N	42	38	70	45	32	—
,, 26	30·37	SW	44	41	76	49	29	—
,, 27	29·95	SW	46	45	—	50	32	—
,, 28	29·75	W	52	48	80	59	46	—
,, 29	29·61	SW	54	49	85	59	45	—
,, 30	29·59	W	45	43	84	55	33	0·55
,, 31	29·68	W	46	43	77	51	39	0·12

⁂ At 2 A.M. the barometer remained steady at 29·68.

257. **Climate.**—Climate may be defined as the average phenomena of the weather which prevail for a considerable period of time in any given place; or in other words, the general state of the atmosphere in regard to heat and moisture and those other meteorological conditions that exert an influence on animal and vegetable life. The four chief causes that determine the climate of any place are—*distance from the equator*, *height above the sea level*, *distance from the sea*, and *prevailing winds*. On all these elements many remarks have been made already, but it will be convenient in this place to gather together some of the chief points connected with each.

258. *Distance from the Equator.*—As already explained, the nearer a place is to the equator, the more vertical do the sun's rays fall upon it, and consequently the greater is the amount of heat it receives (see par. 210). Hence we find that in general the heat is greatest in the equatorial regions, and that there is a progressive gradual diminution with increase of latitude to the extreme cold of the poles. If the earth's surface were uniform, and

if there were no motions in the atmosphere, these gradations would run parallel with the lines of latitude. But on looking at the maps showing the isotherms for January and July it will at once be seen that they are far from being parallel to the lines of latitude. Hence other causes must be at work modifying this great general cause. The movements of the earth as influencing the temperature on its surface will be treated of in the last chapter.

259. *Height above the Sea Level.*—The law of decrease of heat with ascent above the level of the sea has been explained in a previous paragraph, and accordingly we can understand the remark of Sir John Herschel when he says,—

'Thus it happens that, in ascending a mountain from the sea level to the limit of perpetual snow, we pass through the same series of climates, so far as temperature is concerned, which we should do by travelling from the same station to the polar regions of the globe; and in a country where very great differences of level exist we find every variety of climate, arranged in zones according to the altitude, and characterised by the vegetable productions appropriate to their habitual temperatures.'

It is owing to this cause that the climate of hill regions in tropical countries is milder and more salubrious than that of the plain. Some of the European residents in India regularly retire in the hot season to Simla, a station on the slopes of the Himalayas, 7,000 feet above the sea level. Table-lands everywhere illustrate the influence of elevation in the diminution of temperature below the average proper to the latitude, and at the same time the liability to seasonable extremes. The climate of Central Spain, a region which exhibits naked and treeless plains, lying at an elevation of 2,000 feet and upwards above the sea, is very hot in summer and correspondingly cold in winter. Madrid is situated on this inland tableland, and has a difference of 33° between the mean summer and winter temperatures; while Lisbon, in nearly the same latitude, only shows a difference of 18°. The table-lands of Persia and Afghanistan show a similar wide range of temperature, with an average temperature less by many degrees than the lowlands at the same latitude. Quito is situated on a plain under the equator at an altitude of 9,000 feet above the sea. It enjoys nearly the same average temperature as the temperate zones. But even where the average temperatures of a plateau and a lowland in the same latitude are about the same, a great difference exists between the summer and the winter temperatures when the plateau is at a distance from the sea.

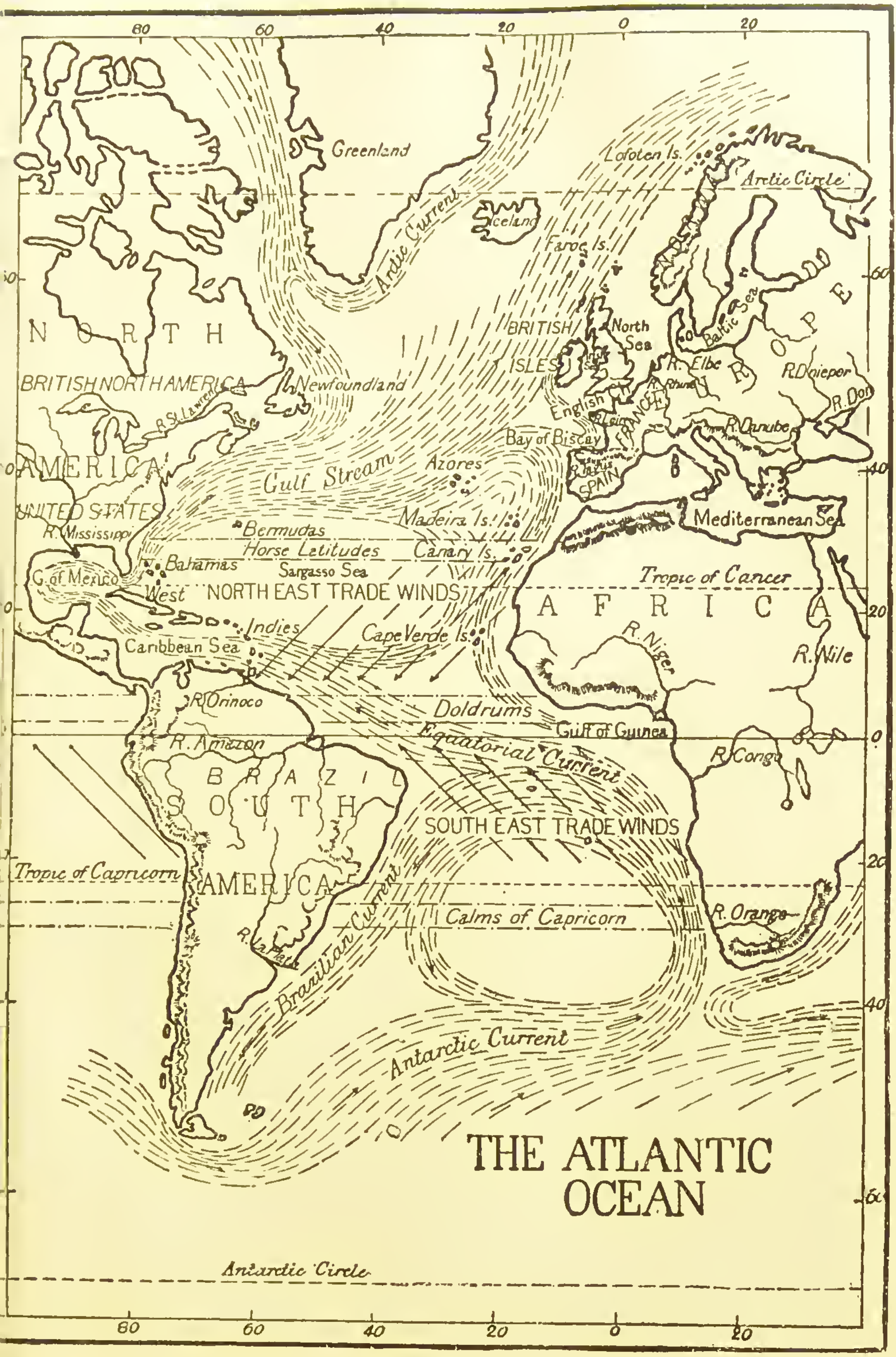
260. *Influence of the Sea on Climate.*—The ocean acts as a great moderator of temperature. As the rays of the sun penetrate the water to a much greater depth (500 feet) than they do the land, and as much of the sun's heat is used up in evaporation, water is much more slowly heated than land. Besides, it requires four times as much heat to raise the temperature of the water one degree as it requires to raise the surface of the ground the same amount (see par. 63); and since substances that absorb heat slowly also radiate slowly, the sea is much more slowly cooled by radiation than the land. In winter the sea slowly gives up the warmth stored up throughout the summer, while in summer the cool breezes blowing from it temper the heat on the land. Hence the temperature of the sea is much more equable than that of the land. These different heat properties of land and water give rise to three classes of climate—*Oceanic*, *Insular*, and *Continental*. Oceanic climates are those which are regulated

entirely by the sea at the given place. They are only to be found on board ships or on small islands. They show for the same latitudes the least differences between the mean temperatures of the different hours of the day and the different months of the year. Some of the island groups in the Pacific, even within the torrid zone, enjoy a most equable climate, the thermometer not varying more than five or six degrees during the twelve months. This is due to ever-blowing breezes from the sea, the surface temperature of which in the tropics shows but little variation throughout the year.

Insular climates are those in which the annual range of temperature is small because the presence of the ocean diminishes the heat of the summer and the cold of winter.

Continental climates are those in which there is a great range of temperature from summer to winter, and the maps of the isotherms show the suitability of the term. Great Britain and New Zealand are examples of insular climates, the summers not having the intense heat, nor the winters the great cold, that inland districts in the same latitude have. As an example of a continental climate we may cite that of Central Russia. Edinburgh and Moscow are in nearly the same latitude. The mean summer and winter temperatures of Edinburgh are 57° F. and 38° F. respectively; of Moscow, the temperatures are at the same seasons 64° and 15°. Thus there is a difference of range of only 19° at Edinburgh and 49° at Moscow. The freedom from the great extremes of Moscow gives to Edinburgh a great advantage. This influence of the sea and other large bodies of water has been put into the following statement by Dr. Haughton:—'Large masses of land, anywhere, increase the range of annual temperature; and large masses of water, anywhere, diminish the range of annual temperature.' The inspection of the maps on which the January and July isotherms are laid down for every ten degrees furnishes instructive proof of this statement, as well as of other causes that operate in the distribution of temperature. Compare, for example, the position of the isothermal line of 60° in the Atlantic Ocean, and in the Old World, during these two months; or compare the temperature of a point in mid Atlantic and in Central Asia at these periods. Near Yakutsk, in Siberia, there is a small district with the enormous range of 100° F. At Yakutsk itself there is a temperature of 65·8° in its warmest month; while in the coldest the temperature is $-44{\cdot}9°$, or 76·9° below freezing-point. But the influence of the sea is also exerted by means of currents. The cold Arctic current that flows from the north past the coast of Labrador accounts not only for the fogs so prevalent, but also for the great coldness of the country when compared with the countries on the opposite coast of the Atlantic, that are washed by the warm waters drifted from the Gulf Stream. The influence of this stream renders the western coasts of Great Britain far more temperate than they would otherwise be, raising the winter temperature several degrees. Its influence is exerted not only by the waters that strike the shore, but more effectively by the winds that blow from its surface. On the Faroe Islands, several hundred miles north of Scotland, it has even a more striking effect. High as is their latitude, snow hardly ever remains, even on the highest hills, for more than a few days.

261. *Influence of Prevailing Winds.*—Winds are one of the most influential of the causes affecting climate. Being warm or cold, wet or dry, according to the district in which they have their origin, and according to the nature of the surface, sea or land, over which they have traversed, it is plain that the prevailing winds determine to a large extent both tempera


80
60
40
20
0
20
Greenland
Arctic Current
Iceland
Lofoten Is.
Arctic Circle
Faroe Is.
NORWAY
BRITISH ISLES
North Sea
Baltic Sea
EUROPE
R. Elbe
R. Rhine
R. Dnieper
R. Don
English Ch.
R. Loire
FRANCE
R. Danube
Bay of Biscay
R. Tagus
SPAIN
Mediterranean Sea
NORTH AMERICA
BRITISH NORTH AMERICA
R. St. Lawrence
Newfoundland
UNITED STATES
R. Mississippi
G. of Mexico
Gulf Stream
Azores
Madeira Is.
Bermudas
Horse Latitudes
Canary Is.
Bahamas
Sargasso Sea
West Indies
NORTH EAST TRADE WINDS
Tropic of Cancer
AFRICA
Caribbean Sea
Cape Verde Is.
R. Niger
R. Nile
R. Orinoco
Doldrums
Gulf of Guinea
R. Amazon
Equatorial Current
R. Congo
BRAZIL
SOUTH AMERICA
SOUTH EAST TRADE WINDS
Tropic of Capricorn
Brazilian Current
Calms of Capricorn
R. Orange
R. La Plata
Antarctic Current
THE ATLANTIC OCEAN
Antarctic Circle
60
40
20
0
20
40
60

MAP X.

ture and rainfall (see par. 223). The south-westerly winds that come across the wide Atlantic and strike the shores of Britain and North-western Europe bring warmth and moisture with them. The vapours condensed on the mountains which run along the western sides of the British Islands and the Scandinavian peninsula fall to the earth in heavy showers of rain. During this condensation a large quantity of latent heat is set free to raise the temperature of the air. The importance of rainfall in conveying heat will be seen from the fact that one gallon of rainfall gives out latent heat sufficient to melt seventy-five pounds of ice. Dr. Haughton calculates that the amount of rainfall on the west coast of Ireland, forty-five inches per annum, contributes nearly half as much heat to that district as that furnished by the direct influence of the sun. As an example of the lowering effect on temperature by a cold wind, attention may be called to the southern States of North America, where during a part of the winter northerly blasts from the higher latitudes of that continent often produce winters of excessive severity. Generally speaking, where the prevailing winds are westerly, as in the Northern Hemisphere, and where currents of warm water are flowing in the same direction from the equator, the cold of winter is greatly mitigated, as is shown by the isotherms bending towards the pole. On the east coasts of Asia and America, however, the prevailing winds are northerly and cold, so that there is a great difference between the summer and winter temperature. Thus it happens that the west coasts of the great continents enjoy an insular climate, while the east coasts and the inland districts endure the more trying continental climate.

262. **Minor Causes affecting Climate.**—Among the lesser influences that affect climate may be mentioned *the direction of the mountain chains, the slope of the ground, the nature of the soil, and the degree of cultivation in a country.*

(1) When a mountain chain runs at right angles to the prevailing winds it is plain that the opposite sides of the chain will be differently affected. By intercepting moist winds, the mountains or the edge of a high plateau will favour the production of rain on the windward slope, and dryness on the leeward slope. Examples of this influence have been mentioned in speaking of rainfall. Our own west and east coasts is a familiar example. Mountains also afford shelter from winds. Thus the Alps protect the plains of North Italy from the cold northerly winds that sometimes blow in Germany and Switzerland. On the other hand, the central and southern parts of Russia, having no protecting range in the north, are much colder than their latitude would lead us to expect.

(2) The effect of the general slope of the land may be noticed in a small scale in the case of gardens. Those with a southerly or western inclination receive the sun's rays more perpendicularly, and being thus more heated, produce fruit and vegetables in more profusion than those with a northerly or easterly inclination. When the sun is elevated 45° above the horizon, his rays will fall at right angles on a hill facing the south at an equal angle ; while if the north side has a similar slope the rays will run parallel to the surface, and their effect will be very small. Since the warmest part of the day is not at noon, when the sun is highest, but, owing to the accumulation of the heat, at about three o'clock, it follows that in our hemisphere a south-south-west or south-western aspect is most favourably situated. The effect of aspect or slope is most strikingly seen in mountain countries where the ranges run in a general easterly and westerly direction,

'The Alps encounter on parts of their southern slope as direct a heat as that which burns up the Desert of Sahara; and on their northern they are as much hidden from the sun's influence as are the level snows of Lapland. In the Alps of the Valais, on the one side you may see the vine in luxuriant growth when the other is thick-ribbed with ice. Thus, too, the terraces and sloping plains which descend from the vast table-land of Central Asia, where, inclining from its northern limit, they pass into the steppes of Siberia, present, under the latitude of Edinburgh, a cold intense enough to freeze mercury; whilst upon the southern terraces of the opposite Himalaya slope flourish, at different elevations, the pineapple, the mango, the gigantic cotton-tree, and the saul. This tropical vegetation ascends then to an altitude of 4,000 or 5,000 feet, mingling itself, and by degrees giving way to the plants of a temperate region—elms, willows, roses, and violets; destined in their turn, at a yet higher region, to yield to Alpine forms of vegetable life.'—*Professor Moseley.*

(3) *The nature of the soil* affects climate through the different heat-absorbing and heat-radiating powers of various rocks. A sandy waste such as the Sahara Desert suffers from great extremes of temperature. In the day the sand absorbs great quantities of heat and becomes extremely hot, but after sunset it cools rapidly by radiation of its heat into the dry atmosphere, so that the nights become very cold. Wet, marshy grounds lower the mean temperature, the water absorbing the heat and conveying it downwards into the ground.

(4) *Degrees of Cultivation.*—Cultivation tends to make a climate drier, warmer, and more salubrious. In uncultivated districts the rivers extending themselves over the low grounds form pestilential marshes. The draining of these marshes and the cutting down of the forests gives the sun free access to the soil, and allows a freer circulation of the air. Many parts of Europe now enjoy a milder climate than formerly, when they were covered with dense forests and full of swamps. There may, however, be too great a destruction of trees, and the quantity of moisture in the air reduced too much (see par. 225).

CHAPTER XIV.

GENERAL IDEAS OF THE CHANGES WHICH THE EARTH'S SURFACE HAS UNDERGONE.

263. **Primitive Condition of the Earth.**—Into the question of the origin of the earth as a separate and independent body we do not propose to enter further than to state that it is believed by many thinkers to be one of a number of masses of matter detached from the sun, and to have passed from the condition of a gigantic gaseous ball, slowly cooled by contact with celestial space, to that of a highly heated fluid mass. That it was once in a viscous or semi-solid condition is proved by its present shape. It is not a perfect sphere, but what is called an oblate spheroid. There is a bulging about the equator,

and a flattening at the poles, so that the equatorial diameter is 26 miles more than the polar diameter. Now it can be proved by mathematics that a plastic body revolving on its axis must assume this shape. We can also illustrate this effect of rotation in the following ways. If a quantity of oil be placed in a transparent liquid it is seen floating in the midst of the fluid as a perfect sphere, just as the earth floats in space ; but as soon as the oil is made to rotate by means of a wire passed through it the spherical form gives place to a spheroidal or elliptical one. Another experiment to illustrate this effect of rotation is the following. An iron rod is fixed upon a turning table, and at the bottom of the rod are fastened four elastic strips of metal, which are joined at the top to a ring capable of sliding up and down the rod. When the apparatus is made to rotate rapidly the upper ring slides down the rod, and the more rapid the rotation the further does the ring slide down. At a great speed the impressions of the separate strips run together so as to give to the eye the appearance of an oblate spheroid, as shown in the figure. We are thus driven to the conclusion that the earth was once in a highly heated fluid condition, and that though a cooling body, it has not yet become cold (see par. 155 on the Internal Heat of the Earth). When in this highly heated state the atmosphere or gaseous envelope would contain many volatile substances now found in a liquid or solid state, and all the water would exist in this atmosphere. As the temperature was sufficiently reduced various chemical combinations of the gases surrounding the earth would take place, and the earliest oceanic areas would become occupied by the condensed steam and alkaline vapours that were previously above the surface One of the substances thus produced and carried into solution by the condensed aqueous vapour was probably sodium chloride so that the saltness of the sea to some extent was produced at

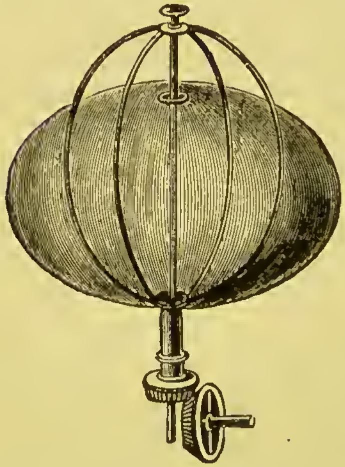


FIG. 122.—Explanation of the Spheroidal Form of the Earth.

this far distant period. Little sodium chloride is now brought by the rivers, as there is little left in the rocks, and the calcium carbonate and silica which they carry down in solution is prevented from increasing by the various animals that secrete it for their shells, &c. The outer crust that formed would consist of such crystalline rocks as granite, and would often be subject to violent disturbances, due partly to the expansive force of the great internal heat, partly to the steam generated when water passed into the fissures, and partly to the continued contraction and shrinking of the crust. Possibly about this period the nucleus of some of the great mountain chains may have been upheaved, and the greater oceanic beds formed, though, as the process of contraction has proceeded down to the present day, it is impossible to fix a time in all cases. But that this contracting force has uplifted, fractured, and contorted rocks during nearly all ages there can be little doubt.

'Of the original crust of our globe,' says Professor Hull, 'we have probably no example on any part of its present surface. It has been either worn down, and supplied materials for newer formations, or it may have been in other places remelted by high internal heat when buried beneath accumulations of sediment, and converted into more modern granites or other igneous rocks. The oldest known formations are marine sediments, which subsequently to their deposition have been completely altered in their character and composition, and belong to the class of rocks known as metamorphic. It is not impossible that the original sediment of which these oldest known strata were formed may have been derived from the waste of the original crust, but more than this cannot be stated with certainty.'

264. **History of Stratified Rocks.**—With the condensation of water on the surface of the earth there would begin that process of denudation described in Chapter XII., and from the detritus of the rocks forming the first crust of the earth, stratified deposits would begin to be laid down. The greatest part of the superficial region of the earth is composed of such formations, and they are called *stratified* on account of their arrangement, *sedimentary* on account of their origin. They represent the deposits of the sea from the remotest periods, and are chiefly made up of the consolidated pebbles, sand, and mud of old sea bottoms. They were accumulated much in the same way as they are now being formed—the pebble beds near the shore, the sandstones a little distance out, and the clay and shale at a still greater distance. In the depths of the ocean after a long period were formed from the remains of animals those calcareous beds known as chalk and limestone. All these deposits were successively piled one above another, so that the oldest are situated at the greatest depth, unless some later movement has come to modify the normal arrangement. Great movements have occurred during the vast ages when the stratified rocks were being formed from the continual waste of land by rain, rivers, glaciers, and the

sea; and there is evidence to show that nearly all parts of what is now land have been again and again submerged beneath the ocean, and that the various sea deposits have again and again been raised high into the air. Even yet the movements of the earth's surface have not ceased, as is shown by the rising and sinking of different areas, and by the various forms of volcanic activity. But in earlier periods of the world's history these internal movements were more active. Igneous rocks have been pushed up in dykes, veins, and bosses amidst the stratified rocks in many districts, or they have been poured out in lava-flows, or ejected as ashes from volcanoes. Thus the original horizontal stratification has been frequently disturbed, and the strata are in many cases bent, crumpled, folded, and fractured in extraordinary ways. The relative ages of the various stratified rocks have been determined in several ways. When one stratum rests upon another we infer that the lower bed was formed before the deposition of the upper bed began. Thus, by observing how strata rest upon one another in cliffs, ravines, cuttings, mines, &c., an order of succession of the stratified rocks begins to be made out. Their mineral composition also assists in determining their age. But the greatest help in constructing a table to show the order of succession is derived from fossils, as the remains of animals and plants buried in the rocks are called. The special fossils that characterise the different strata have been ascertained, and it has been discovered that each age of the world had its own peculiar groups of animals and plants—its *fauna* and *flora*. From such considerations geologists have divided the various strata of the world into three great groups, the oldest being called the Primary, the next the Secondary, and the last group the Tertiary. Corresponding to these great groups of stratified rocks are three great epochs or periods of time—Palæozoic (Gr. *palaios*, ancient; *zoe*, life), Mesozoic (Gr. *mesos*, middle; *zoe*, life), and Cainozoic (Gr. *kainos*, recent; *zoe*, life). Each of these great groups of strata is divided into smaller groups called *formations*, a formation being a group of stratified rocks which have certain characters of age and composition in common. The formations included in these three great divisions are shown in the following table:—

Periods	Formations
Tertiary or Cainozoic	Pliocene
	Miocene
	Oligocene
	Eocene
Secondary or Mesozoic	Cretaceous
	Jurassic or Oolitic
	Triassic
Primary or Palæozoic	Permian
	Carboniferous, or Coal Measures
	Devonian and Old Red Sandstone
	Silurian
	Cambrian
	Archæan or Laurentian

A fourth period is frequently added above these, and called Post-Tertiary, Recent, or Quaternary. It consists of alluvial and glacial deposits with peat and crag, the earlier portion of the period being called Pleistocene. At the base of these formations the Azoic or lifeless period is sometimes shown. The rocks in this division, of sedimentary origin at first, have been

SECTION OF THE EARTH'S CRUST,

Showing the Geological Formations.

EPOCHS			GROUPS	FORMATIONS
STRATIFIED OR FOSSILIFEROUS ROCKS	CAINOZOIC	QUATERNARY	Modern Deposits. *Alluvium of Rivers, Lakes, and Seas. Clays, Sands, Gravels. Peat-mosses.*	Post-Tertiary
			Newer Pliocene, or Pleistocene. *Drift Boulder, Glacial Beds, Shell Marl, &c.*	
		Tertiary	Pliocene. *Red Crag, Coralline Crag, &c.*	Upper Tertiary
			Miocene. *Bovey Tracey Beds.*	Middle Tertiary
			Eocene. *Fresh-water Beds, Bagshot Sand, London Clay, &c.*	Lower Tertiary
	MESOZOIC EPOCH	Secondary Strata	Chalk and Chalk Marl. *Upper Greensand and Gault.* Upper	Cretaceous
			Cretaceous. *Lower Greensand.* *Kentish Rag.* Lower	
			Wealden. *Weald Clay, Hastings Sand.*	Oolitic or Jurassic
			Upper Oolitic. *Purbeck Beds, Portland Stone, Kimmeridge Clay.*	
			Middle Oolitic. *Coral Rag, Oxford Clay.*	
			Lower Oolitic. *Cornbrash and Forest Marble, Bradford Clay.* *Great Oolite.* *Fuller's-earth.* *Inferior Oolite.*	
			Lias. *Upper Lias Shale, Marlstone, Lower Lias Clay, and Lime.*	
			Trias or Upper New Red Sandstone. *Variegated Marls with Salt and Gypsum. Variegated Sandstones, &c.*	Triassic
	PALÆOZOIC	Primary	Permian. *Magnesian Limestone, Lower New Red Sandstone.*	Permian
			Upper Coal Measures. *Millstone Grit, Carboniferous Limestone.* *Lower Coal Measures.*	Carboniferous
			Devonian or Old Red Sandstone.	Devonian
			Upper Silurian. *Wenlock Limestone, Ludlow Rocks, Tilestones.*	Silurian
			Lower Silurian. *Bala Beds, Caradoc Sandstone, Llandeilo and Lingula Flags, Tremadoc and Festiniog Slates.*	
			Cambrian. *Longmynd or Bangor Slates, Llanberis Slates, Harlech Grits.*	Cambrian
			Laurentian. *Consisting of highly crystalline Gneissoid and Hornblendic Schists.*	Archæan
AZOIC OR HYPOZOIC			Metamorphic Rocks. *Gneiss, Quartzite, Mica Schist, Clay Slate, &c.*	Metamorphic of different ages
IGNEOUS OR UNSTRATIFIED ROCKS			Volcanic: *Lava, Pumice, Tufa, Basalt, and other Erupted Rocks.* Plutonic: *Granite, Syenite, &c.*	

so changed or metamorphosed by heat, water, and pressure, that they contain no traces of any living beings. The mineral structure of these metamorphic rocks has been described in par. 144. They are of all ages, the change being produced wherever contact with the intrusive and erupted igneous rocks has occurred. The formations are divided into still smaller groups, according to their mineral composition and other peculiarities. The table on page 193, which exhibits an ideal section of the earth's crust, will assist in giving the pupil some idea of the groups included in the different formations, and of the nature of the rocks comprising these groups. The palæozoic or primary rocks generally possess a more slaty and crystalline structure than those of later groups. Their total thickness has been estimated at 78,000 feet, while the thickness of the other strata in England and Wales is reckoned at about 15,000 feet.

There is thus a definite and unfailing order of succession in the various stratified deposits that form the chief part of the known earth's crust.

'To sand and gravel succeed, proceeding downwards, various clays; below clay comes chalk; below that again various limestones, known (from the nature of their component particles) by the term oolite; lower down certain sandstones; below them carboniferous limestones; lower still old red sandstone, or "Devonian" rocks; and yet lower in position the slaty and other rocks designated as Silurian. The succession is, indeed, often interrupted, some of the intermediate series being absent; that is, sandstone of the upper series may immediately succeed clay, the intermediate chalk and other strata being absent, and so forth; but the order in which various members of the series are found, relatively to one another, undergoes no variation. The chalk, wherever it occurs, is inferior in position to the clays and gravels, the oolitic limestone to the chalk, and so on.'

A practical use may be made of this knowledge of the order of succession. If, for example, the formation at the surface be older than the carboniferous, we know that coal cannot be found beneath. But if the rocks at the surface be newer, we do not infer from that alone that coal will be found, for the carboniferous or coal measures formation may be wanting in that district. But it must not be supposed that these rocks are everywhere horizontally arranged, for the upheaving forces that operate from below having frequently tilted them at various angles, the denuding forces may have been removing beds in one part, while deposition has been going on in another. Thus it happens that the edges of successive strata often appear at various angles at or near the surface, so that on a hill-side, in a deep valley, or even on an open plain, we may see various kinds of rock cropping out. The diagram above will assist the pupil in understanding this, though it must not be supposed that the parallel arrangement of strata here shown, nor the comparative equality in point of thickness, is often met with in nature. If the pupil will look at the geological map of England (or any other country), on which the various formations that come

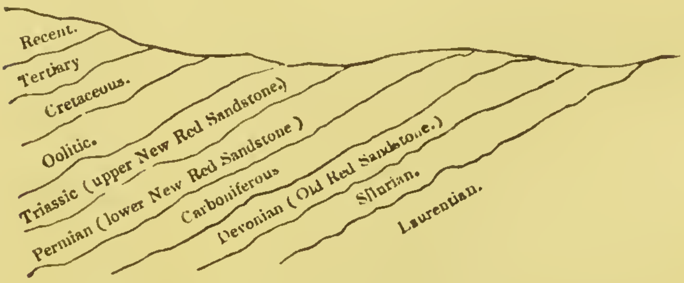

Recent.
Tertiary
Cretaceous.
Oolitic.
Triassic (upper New Red Sandstone.)
Permian (lower New Red Sandstone)
Carboniferous
Devonian (Old Red Sandstone.)
Silurian.
Laurentian.

FIG. 123.

to the surface are indicated by different colours, he will understand the general arrangement of the strata still better. Bearing in mind that the boulder clay and drift occurring here and there in patches, and left when the country was covered with an ice-cap, are not represented on such a map by colours, but that the various colours are only intended to show the class of rock that underlies the superficial accumulations of soil and gravel, a journey from east to west across the central part of the country would show that successive strata come to the surface in a very striking order.

'Broadly speaking, the northern and western parts of England and the greater part of Wales are formed of the older rocks, known as Primary or Palæozoic. These were considerably folded and disturbed before the newer rocks were laid down. Resting on their upturned edges, or abutting against them, lie the Secondary strata, which form a group dipping generally in a south-easterly direction, so that in passing from north-west to south-east we come successively on higher and higher beds, from the Lias, which stretches from Lyme Regis in Dorsetshire to Whitby in Yorkshire, to the Chalk, which runs from Dorsetshire and Hampshire to Flamborough Head. The older Tertiary beds repose on the chalk in the irregular areas known as the London and Hampshire basins; and they were together much disturbed and denuded before the newer Tertiary or Pliocene strata were laid down on the western borders of the German Ocean. The Quaternary deposits form a distinct group, scattered irregularly over the country and resting indifferently on any of the rocks, from the oldest upwards.' [1]

The igneous rocks that reach the surface in England are chiefly found in Devonshire and Cornwall, and amid the Cumbrian mountains.

265. **Fossils** (Lat. *fossilis*, dug out) are remains, or traces of remains, of plants and animals which we find buried in the crust of the earth. They only occur in the stratified rocks, where they were deposited at the time the rocks were forming, just as we might now find in the beds of lakes and seas the buried bodies of the animals now existing. From the more perishable nature of plants it is evident that their remains would not be so well preserved as those of animals. These remains consist sometimes of the shells, bones, teeth, or other hard parts of the original substance of the animals or plants; but more frequently, especially in the older strata, the original matter has been replaced particle by particle by mineral matter of a different composition, so that an exact model of the form is left in a different material. In other instances a cast or mould only of the object is preserved. Thus not only are shells, bones, trunks of trees, &c., whether mineralised or not, called fossils, but impressions and footprints are included in the word. These fossil forms were known for a long time, but for many generations their true nature was not understood. They were believed to be 'freaks of nature,' or products of a universal deluge, until geologists showed that they were in fact organic remains. Traces of this belief are left in some of the names which were first applied to the relics. Thus in several of the older rocks, as the chalk formation, long conical fossils

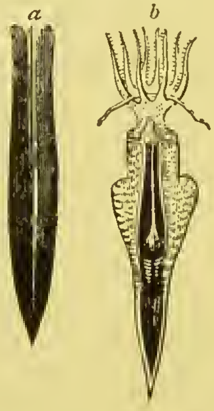


FIG. 124.—Belemnites. *a*, B. acutus. *b*, Belemnite (restored).

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[1] *The Geology of England and Wales*, by Horace B. Woodward, F.G.S., p. 26, second edition, 1887.

called *belemnites* are found. The word is from the Greek, and means a *dart*, as the ancients believed them to be the thunderbolts of Jove. They are now known to be the petrified internal bones of a race of ten-armed cuttle-fishes.

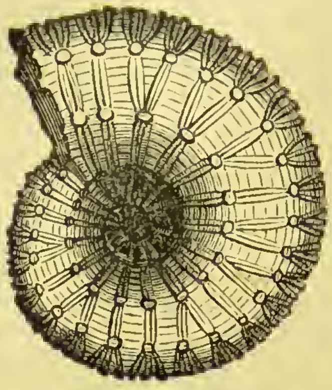

FIG. 125.—Ammonite.

Another well-known fossil, called the *ammonite*, received its name from a resemblance to the horns on the statue of Jupiter Ammon. They are popularly known as *snakestones*. The ammonite is the fossil shell of an extinct kind of molluscous or soft-bodied animal that inhabited a chambered shell curved like a coiled snake. Ammonites vary in size from a small button to a coach-wheel. Many of the shells must have been beautifully marked. Both ammonites and belemnites are extinct, having disappeared with the cretaceous period. But among the fossil remains none are more strange than the immense Saurians, an order of reptiles that inhabited the seas of the Mesozoic period. Fig. 126 shows the remains in a rock of one of these reptiles, called the ichthyosaurus. It was a huge creature from thirty to fifty feet long, half fish, half lizard, with a snout like a porpoise, teeth like a crocodile, and paddles like the whale. Each rocky stratum is, in fact, distinguished by its fossils, or at least by certain of its fossils; and thus the fossils serve to mark out the place which the stratum occupies in the series of stratified rocks. Moreover a naturalist can tell whether the fossil shell (for shells are the most abundant fossils) was that of a fresh-water mollusc, of a mollusc that inhabited the brackish water near the mouth of a river, of a marine mollusc, or of a terrestrial mollusc. This is one of the ways in which the geologist ascertains whether a bed of rock was formed out of the ooze drifted over a lake, or out of the sand deposited in an estuary, or out of the layers spread over the bottom of a former sea. The illustration on the next page gives a diagram of the stratified rocks, with figures of some of the characteristic fossils of each formation.

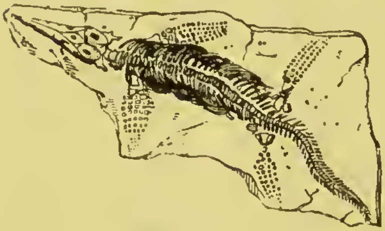

FIG. 126.– Ichthyosaurus communis.

266. **Progress of Life.**—Life began among plants in simple *seaweeds*, and these were followed by *lycopods* (plants intermediate between mosses and ferns), *ferns*, and other *flowerless* plants. To these succeeded the lowest kind of *flowering* plants, and finally there appeared palms, oaks, the ash, the elm, the orange, the rose, and others of the higher flowering species. Among animals life began with simple invertebrates. Foraminifera,[1] molluscs, corals, and trilobites are abundant in the earliest formations. The trilobite, of which there were many classes, was an

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[1] The earliest known fossil is a supposed foraminiferal form called *Eozoon canadense*. It is found in the Laurentian rocks of Canada. The dark layers in the figure are thought to mark the position of the animals. Many geologists, however, believe that the marks are of mineral origin only.

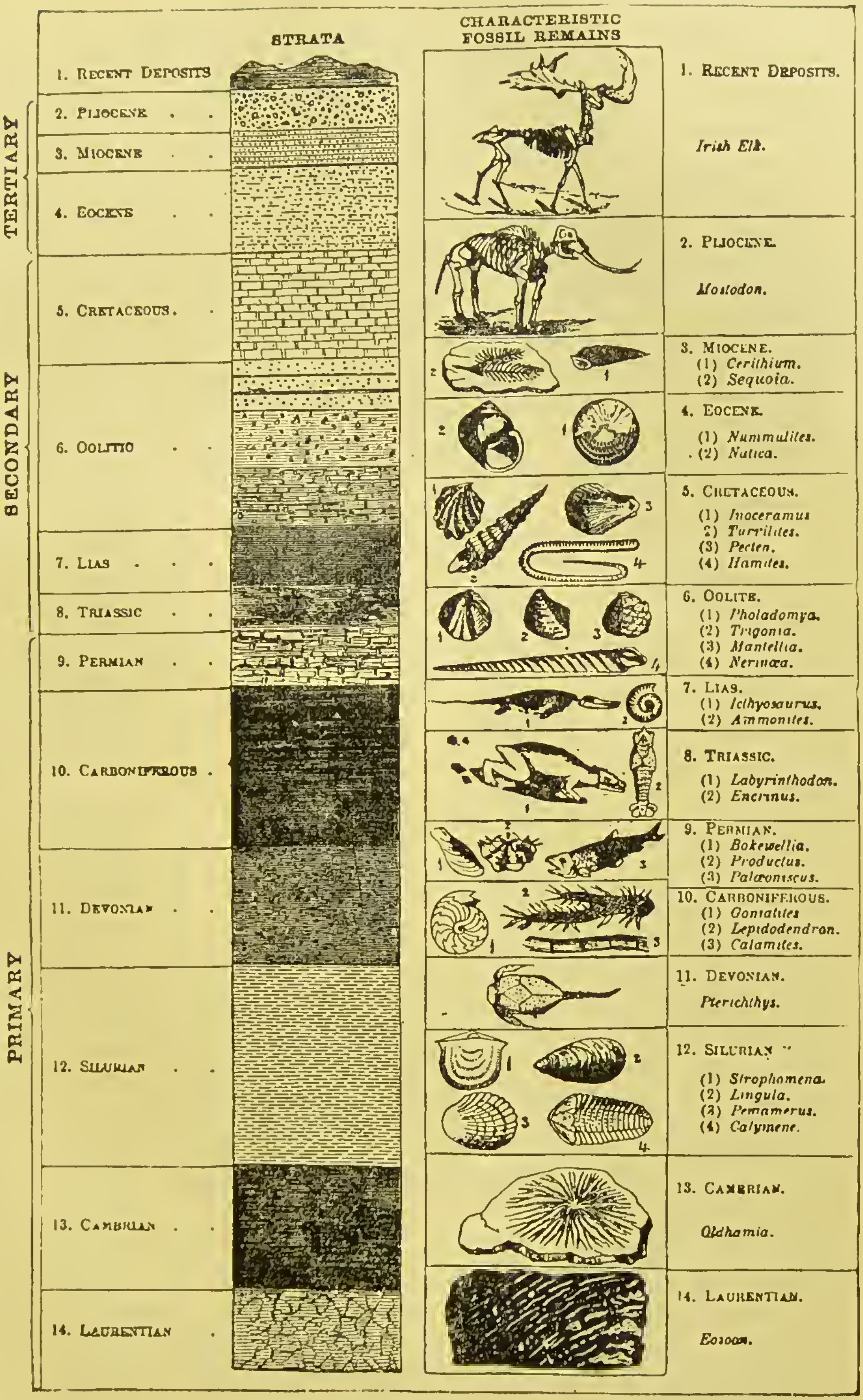
STRATA
CHARACTERISTIC FOSSIL REMAINS
TERTIARY
SECONDARY
PRIMARY
1. Recent Deposits
2. Pliocene
3. Miocene
4. Eocene
5. Cretaceous
6. Oolitic
7. Lias
8. Triassic
9. Permian
10. Carboniferous
11. Devonian
12. Silurian
13. Cambrian
14. Laurentian
1. Recent Deposits.
Irish Elk.
2. Pliocene.
Mastodon.
3. Miocene.
(1) Cerithium.
(2) Sequoia.
4. Eocene.
(1) Nummulites.
(2) Natica.
5. Cretaceous.
(1) Inoceramus
(2) Turrilites.
(3) Pecten.
(4) Hamites.
6. Oolite.
(1) Pholadomya.
(2) Trigonia.
(3) Mantellia.
(4) Nerinæa.
7. Lias.
(1) Ichthyosaurus.
(2) Ammonites.
8. Triassic.
(1) Labyrinthodon.
(2) Encrinus.
9. Permian.
(1) Bokewellia.
(2) Productus.
(3) Palæoniscus.
10. Carboniferous.
(1) Goniatites
(2) Lepidodendron.
(3) Calamites.
11. Devonian.
Pterichthys.
12. Silurian.
(1) Strophomena.
(2) Lingula.
(3) Pentamerus.
(4) Calymene.
13. Cambrian.
Oldhamia.
14. Laurentian.
Eozoon.
1
2
3
4

Fig. 127.

animal belonging to the same family as the shrimps, but much larger. Its hard shelly covering is frequently found as a fossil in some of the rocks of the Palæozoic period, but it disappeared in the Carboniferous period. Afterwards there came an age when worms and fishes were numerous. The Devonian age has been called the Age of Fishes, as they were so numerous in that period. In this period also there appeared the first air-breathing animals, in the form of insects. During the Carboniferous period the land was covered in many places with the huge ferns, club-mosses, shrubs, and trees out of which the coal beds have been formed. Besides the classes of animals already mentioned, a higher group of vertebrates, called Amphibians, were abundant at this time. Amphibians, as frogs and salamanders, are intermediate between fishes and reptiles. They breathe by gills in early life, and by lungs in the adult stage. In the Permian period, reptiles, which are vertebrate animals that breathe by lungs during their whole life, make their appearance, and they were so abundant during the Secondary or Mesozoic period that it has been called the Age of Reptiles. The great lizard-like Saurians, of which the ichthyosaurus is an example, especially characterise the Jurassic strata. After this period the reptiles dwindled, and the higher class of animals, known as mammals or quadrupeds, roamed over the continents. The earliest fossil birds belong to the Jurassic period. For many ages the birds had teeth, and it was not till Eocene times that true birds existed.

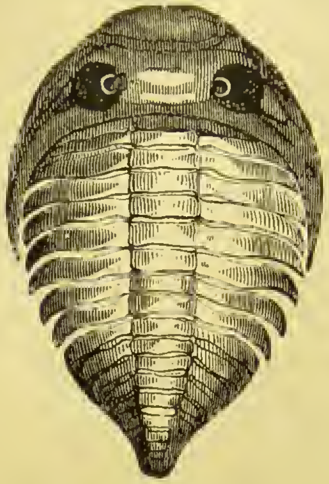

FIG. 128.—Trilobite.

During the Eocene period numerous extinct species of coin-shaped Foraminifera, called Nummulites (Lat. *nummus*, a coin) inhabited the waters. Their fossil shells, which consisted of spirally arranged chambers, and which varied in size from an eighth of an inch to an inch, form beds of nummulitic limestone.

It was not until the Quaternary period that the most highly organised animal, man, appeared. He seems to have followed the period of great cold called the Glacial period, and to have been contemporary with the extinct mammoth, cave hyena, cave lion, and Irish elk. At first his weapons were fashioned out of flint, basalt, and bone. Many of the stone implements used by prehistoric man have been found in various parts of our island, and these become gradually superseded by weapons of bronze and iron. At this comparatively late period history begins. Thus there has been during the history of the earth a constant evolution of higher from lower forms; and though thousands of species have died out, yet the simpler forms have not been wholly destroyed.

267. **Changes of Climate.**—From what has been said about the early condition of the earth, it would appear that the climates of the early geological periods must have been warmer than the present ones. Not only would the sun's heat be greater, so that the earth would probably receive more from that source, but for some time the internal heat of the globe would exert a sensible influence on its surface. Other considerations also indicate that there has been a general lowering of temperature during past geological time, and a general tendency towards greater extremes of climate.

Thus the great extent of fossil fuel found in the coal beds of both hemispheres indicates that during the Carboniferous period there was a uniform warm and moist climate, in which coal plants grew in low marshy situations so luxuriantly that they were able to produce successive accumulations of vegetable matter of great thickness and wide extent. These were from time to time covered over by sediments, and at last mineralised and changed into beds of coal. In the Cretaceous period the climate of the whole of the Northern Hemisphere was of a sub-tropical character, as is proved by the nature of the fossil plants found in the rocks of this period. During this period also the British Isles and many parts of Central and Southern Europe were depressed beneath the sea; in Eocene times the Alps and the Himalayas were raised, and it is not till the close of the Miocene times that the land was elevated into a position very similar to the present. Such changes in land and water surfaces must have produced some effect on climate. But there is evidence to show that towards the end of the Cainozoic or Tertiary period alternations of cold and warm ages prevailed in both hemispheres. The climate of our islands and of the northern part of Europe became as severe as that of the Arctic regions of the present day. Proof of this is abundant in the ice-scratched rocks, erratic blocks, and boulder clay formed of ice-ground material, which may be found so readily in most parts of Scotland, and in Northern and Central England. In fact, the greater part of the country must have been buried under one vast glacier, which as it moved downwards ground away the rocks, transported huge fragments, and produced the great mass of clay and stones now found on the surface of the stratified rocks in so many parts of the country. How long this *glacial epoch* or *ice age* lasted it is not possible to say; that it was not one unbroken period of cold, but that there were one or more warm intervals, seems certain from the remains of forests and animals discovered in the thicker masses of the boulder clay. The cause of these alternations of cold and warm cycles has been attributed to periodical variations in the eccentricity of the earth's orbit, combined with the changes which such variations would cause in the deflection of ocean currents, and other climatic conditions.

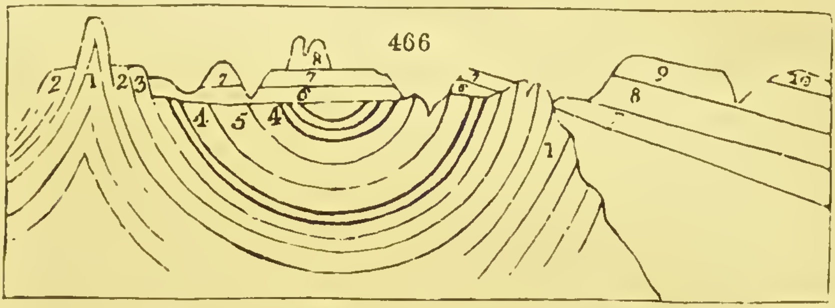

FIG. 129.—Section of Coal-field South of Malmesbury.

1. Old red sandstone.
2. Mountain limestone.
3. Millstone grit.
4. Coal seams.
5. Coarse sandstone.
6. New red sandstone.
7. Lias.
8. Inferior oolite.
9. Great oolite.
10. Corn brash and forest marl.

Regarding *geological time*, little can be said until the pupil has made more acquaintance with the facts of the science. The total thickness of the stratified rocks, if they were all found superposed in any locality, could hardly be less than 100,000 feet, and a very moderate computation requires 100,000,000 of years for their deposition.

CHAPTER XV.

MAGNETISM AND ELECTRICITY OF THE EARTH.

268. **Natural and Artificial Magnets.**—Among the older geological formations of Scandinavia and America an ore of iron having a composition represented by the formula Fe_3O_4 is worked, and from it iron of excellent quality is obtained. This ore in its natural state possesses the peculiar property of attracting iron and some other substances, and is often called magnetic oxide of iron, or the *lodestone* (A.S. *lædan*, to lead). Magnetic iron ore was first found in Magnesia, in Asia Minor, and was called by the Greeks *magnēs*, whence our word *magnet*. *Magnets* are substances that possess the property of attracting iron, and *magnetism* is the name of the science which treats of the causes and phenomena of this attractive property. The ore itself is called a *natural magnet*. When a bar or needle of steel is rubbed by a piece of this magnetic ore it also acquires the attractive property of the ore, and such a bar is called an *artificial magnet*.

269. **Poles and Neutral Lines of a Magnet.**—On dipping a magnetised steel bar into iron filings we notice that the attractive force is not evenly distributed. Tufts of filings cling to the end of the bar, and the number of attracted filings diminishes towards the middle, where none are found. That part of the bar where there is no visible attractive force is called the equator or neutral line, and the parts near the ends of the bar, where the force of attraction is greatest, are called *poles*. The term *poles* or *polarity* is often employed to denote equal and opposite properties in opposite portions of a particle or mass, or 'opposite and antithetical actions, which are manifested at opposite ends of a line of force.'

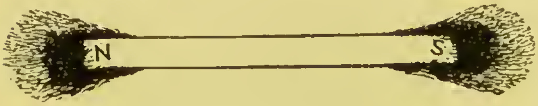

FIG. 130.—Iron Filings attracted by a Magnet.

Every magnet has two poles and a neutral line. If the bar be broken in two, each part will be found to be a complete magnet, with its two poles and neutral line. The magnetic force is exerted not only when the two substances are in contact, but at a distance. The force, however, diminishes according to the square of the distance. It is also exerted through intervening substances. If a sheet of glass or cardboard be placed over a magnet, and filings sprinkled over it, it will be seen that the filings arrange themselves along curved lines from one pole to another. A bar of steel may be bent into a curve like a horeshoe, the poles still remaining near the end, and the neutral line being still in the middle. A keeper is often added to the horseshoe magnet to close the circuit, as in fig. 131.

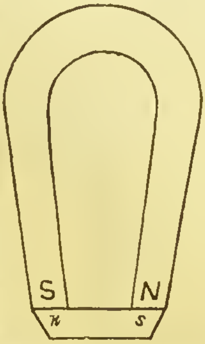

FIG. 131.—Horseshoe Magnet and Keeper.

270. **Magnetic Needles.**—A magnetised steel bar freely suspended at its centre, or freely balanced on a pivot at its centre, is called a *magnetic needle*. Such a magnetic needle assumes a position nearly parallel to the geographical meridian, the line passing through a given place, and through the north and south geographical poles. In other words, one end of the needle points approximately to the north and the other end to the south ; and if the needle be turned in another direction, it will come back to this position. That end of a freely suspended magnetic needle which points to the north is called the North Pole, and the end which points to the south is called the South Pole of the magnet.

271. **Reciprocal Action of Poles.**—If we place the north pole of a magnet near the north pole of a suspended magnet, the latter is repelled; while if we place the north pole near the south pole, the latter is attracted.

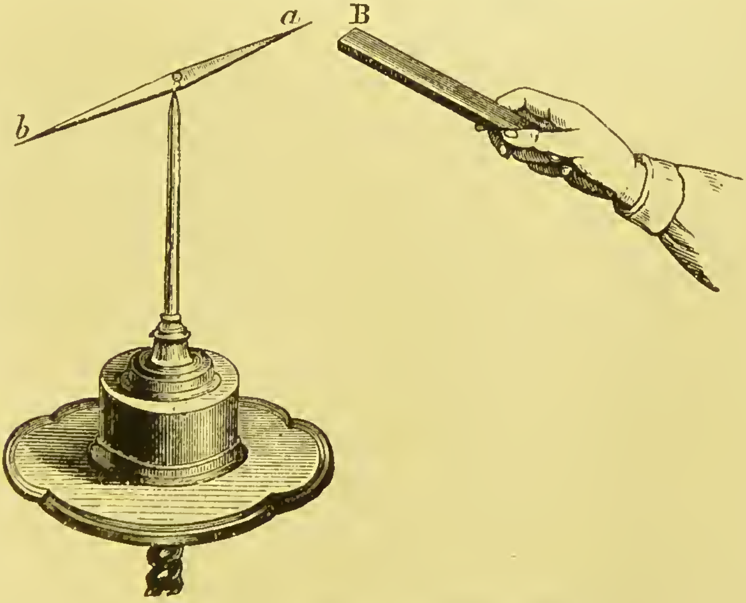

FIG. 132.—Attraction of Opposite Poles.

A similar experiment by presenting the south pole of a magnet to the suspended magnet leads us to the following law :—Like poles *repel*, and unlike poles *attract* one another.

If the similar poles of two equal magnets be brought together, the magnetism of the two will be neutralised, so as to have no effect.

272. **Magnetic Induction.**—When a steel bar has been magnetised, it retains its magnetism for a considerable time, and is spoken of as a *permanent*

magnet. If a bar of soft iron be brought near or in contact with such a permanent magnet, it is also found to have become a magnet.

The action in virtue of which a magnet is thus enabled to develop magnetism in another body is called magnetic induction. Thus, if the magnet B have its north pole brought in contact with a piece of soft iron, it is seen that magnetism has been induced in the iron, the end of the soft iron touching the magnet having an unlike pole produced in it, the like pole being repelled to the other end. Other pieces may be attached to this until the supporting strength of the magnet is reached. Thus the magnet in fig. 133 is seen to have five such pieces attached. When the permanent magnet is withdrawn, the soft iron ceases to exhibit any attractive force, and returns to its neutral condition. Hence it is called a 'temporary magnet.'

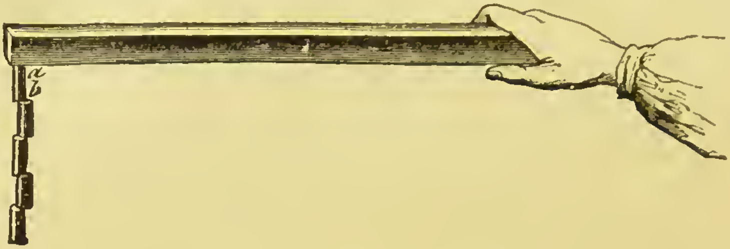

Fig. 133.—Magnetic Induction.

273. **Difference between Magnets and Magnetic Substances.**—A magnetic substance is a substance which is attracted by a magnet. Iron, nickel, cobalt, platinum, oxygen, and several other substances suffer attraction. Magnets are substances which possess the attractive property, and which have the property concentrated at the two poles. A magnetic substance has no poles, and if presented successively to the two ends of a magnetic needle, it will be attracted by both ends equally. A magnet would be attracted at one end and repelled at the other.

274. **The Earth a Great Magnet.**—As already pointed out, a freely suspended magnetic needle, or a needle balanced on a pivot, not only possesses the property of all iron, but also that of setting itself in a definite position—nearly north and south. This is due to the fact that the earth itself is a great magnet. Its poles and neutral line, however, do not coincide exactly with the geographical poles and equator. Like other magnets, the earth attracts the opposite poles of a magnetic needle, and causes the poles of this needle to lie in the direction of the line joining the magnetic poles of the earth. The north magnetic pole of the earth was discovered by Sir James Ross, and is situated in lat. 70° N., and in long. 96° 43′ W. The position of the south magnetic pole has not been found, though from certain calculations it is believed to be in lat. 73° 30′, and in 147° E. long. If, instead of placing the needle on a pivot, we placed it on a cork in a vessel of water, it is found that the needle, after a few oscillations, comes into a position which is in the same direction as that which it had on the pivot. It does not move about, but only sets in a certain direction. Hence the earth's magnetism is simply directive, not translative.

275. **Declination.**—The geographical meridian of a place is the imaginary vertical plane passing through this place and the two geographical poles. It is usually indicated by a line on the surface of the globe. The

magnetic meridian is the vertical plane passing through the two poles of a freely suspended magnetic needle, and which, being produced in both directions, also passes through the magnetic poles of the earth. These two meridians do not coincide, and the angle which the direction of the needle makes with the geographical meridian is called the *declination* or *variation* of the magnetic needle. The declination is said to be east or west according as the north pole of the needle is to the east or west of the geographical meridian. Thus, in fig. 134, *a b* is the direction of the magnetic meridian, and *s n* the direction of the geographical meridian. The angle formed between the two meridians at any place is the declination of the needle at that place. The declination varies at different places. At present it is to the west in Europe and Asia.

It also varies at the same place in the course of time. This steady change in one direction for some years is called the *secular variation* of the needle. Thus, at London,[1] it was found that—

In A.D.	1580	the magnetic needle		pointed	11° 15′ E. of N.
,,	1657	,,	,,	,,	due N.
,,	1818	,,	,,	,,	24° 38′ W. of N.
,,	1887	,,	,,	,,	about 18° W. of N.
,,	1892	,,	,,	,,	17° 12′ W. of N.

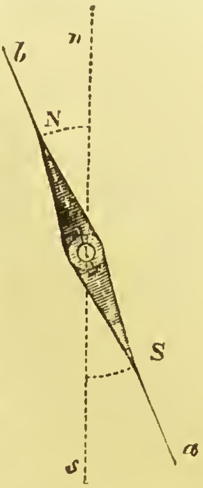

Fig. 134.—Declination of Compass Needle.

There is also a small *diurnal variation* of the needle. This is greatest in summer and least in winter.

Lines connecting those places on the earth's surface at which the declination or variation is the same are called *isogonal lines* (Gr. *isos*, equal; *gonia*, an angle).

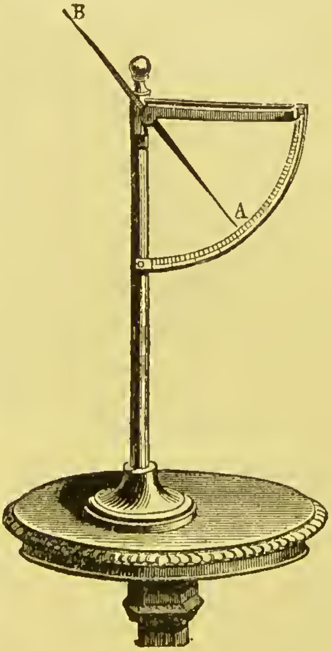

Fig. 135.—Inclination Compass, or Dipping Needle.

276. **Inclination or Dip.**—When a needle is supported on a vertical pivot so as to remain quite horizontal, it is found that on being magnetised it no longer remains horizontal, but at London the north end of the needle dips down and forms an angle of about 67° 30′ with the horizontal plane. In order to see the dip accurately the needle must be placed in the magnetic meridian. The angle which a magnetic needle capable of vertical movement makes with the horizontal plane is called the inclination or dip, and a needle so poised is called a dipping needle. The dip varies in different parts of the world. On going north of London the dip increases; on going south the dip diminishes. The magnetic equator of the earth, or neutral line, is the line connecting those places where there is no dip, and the magnetic poles of the earth are the places where the dipping needle is vertical. Lines connecting those places on the earth's surface at which the magnetic dip or inclination is the same are called *isoclinic*

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[1] See par. 290.

lines (Gr. *isos*, equal; *klino*, to incline). The dip undergoes changes in the course of time. At London in 1800 it was 70° 35′, but it has now (1892) decreased to 67° 22′.

The force of the earth's magnetism is least at the magnetic equator, and increases as we approach the magnetic poles. If a horizontally suspended magnetic needle be moved from its position of rest, it will return to its former position after a number of oscillations. This number varies with the position of the place, and it has been proved that the force or intensity of the earth's magnetism at any two places is proportional to the square of the number of oscillations made by the same magnetic needle at these two places. The declination, the inclination, and the horizontal force at any place are called the 'earth's magnetic elements' at that place.

277. **Mariner's Compass.**—An important application of the magnetic action of the earth is made in the *mariner's compass.* This is an instrument used to indicate the magnetic meridian, or the position of objects with respect to that meridian. It consists of a magnetised bar of steel attached to a circular card which turns with it, and the circumference of which is divided into thirty-two parts, called *points* or *rhumbs.* The card is so fixed that the crown or fleur-de-lis is exactly over the north or marked end of the needle. The needle and card are placed in a basin, and supported at the centre on an upright sharp-pointed pivot of steel which fits into an agate cap. In this way the needle and card are capable of moving horizontally in any direction with the least possible friction. The pivot rises from the centre of a glass-covered circular box, which is suspended so that it always retains a horizontal position notwithstanding the rolling of the ship. The compass is placed in a part of a ship called the *binnacle*, in sight of the helmsman.

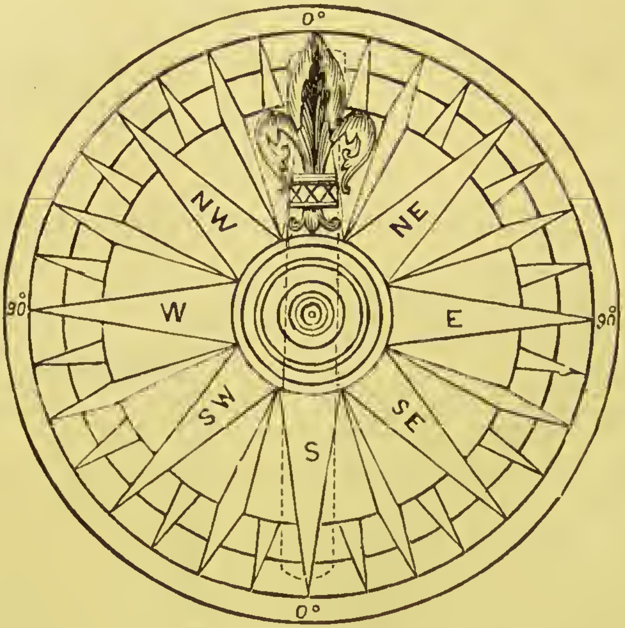

FIG. 136.—Needle and Card of Mariner's Compass.

Inside the compass box or bowl is placed a black line called the *lubber line*, in the direction of the ship's bow, and the helmsman has to keep the point of the card which marks out the ship's course in contact with this line.

In a land compass the magnetic needle is so arranged that it moves in a case above a graduated card. Knowing the declination of the compass at any place, the traveller can determine the geographical meridian, or north and south line, by turning the compass until the needle deviates from the line N S by a quantity equal to the declination.

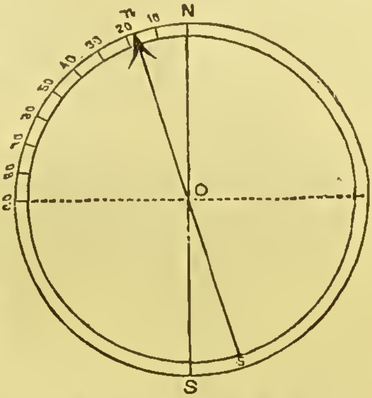

FIG. 137.—Diagram of Land Compass.

The notation of the compass is as follows :—

'The circumference being divided into the four quadrants by two diameters at right angles, the extremities of these diameters are the four cardinal points (*cardo*, a hinge), marked N., S., E., W. (north, south, east, west). Bisecting each of the quadrants, the several points of bisection are denoted by placing the two letters at the extremities of the quadrant in juxtaposition. Thus N.E. (north-east) denotes the point which is halfway between north and east ; and so with N.W., S.E., S.W. (north-west, south-east, south-west). Let the octants next be bisected ; the points of division are denoted by prefixing to each of the above combinations, first the one, and then the other, of the two cardinal points of which it is formed. Thus N.E. gives N.N.E. and E.N.E. (north-north-east and east-north-east) ; and so in respect of the other. Sixteen points have thus been named. Let the distance be again bisected, then each of the points so found is expressed by that one of the preceding points already named to which it is nearest, followed by the name of the cardinal point towards which its departure from the nearest points leads it, the two being separated by the letter *b* (by). Thus the point halfway between N. and N.N.E. is N. by E. (north by east) ; that which is halfway between N.N.E. and N.E. is N.E. by N. (north-east by north) ; &c. The whole of the thirty-two points are thus distinguished, as in the figure.'

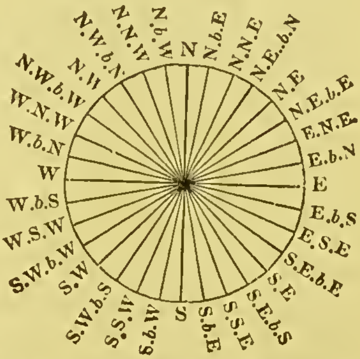

FIG. 138.—Points of Compass.

278. **Electricity.**—'Electricity is a powerful physical agent which manifests itself mainly by attractions and repulsions, but also by luminous and heating effects, by violent commotions, by chemical decomposition,

and many other phenomena. Unlike gravity, it is not inherent in bodies but is evoked in them by a variety of causes, among which are friction, pressure, chemical action, heat, and magnetism.'—*Ganot.*

279. **Electrical Excitation.**—When a glass tube is rubbed with a piece of silk, it acquires the power of attracting light substances, such as little pieces of paper, feathers, and light pith-balls, and if brought near the face it gives rise to a peculiar sensation. A rod of sealing-wax or ebonite rubbed with flannel exhibits similar properties. If the rod be excited in the dark, luminous effects may be observed. This peculiar attractive force has received the name of electricity, from the Greek word *electron*, amber, as it was first excited by the rubbing of this substance.

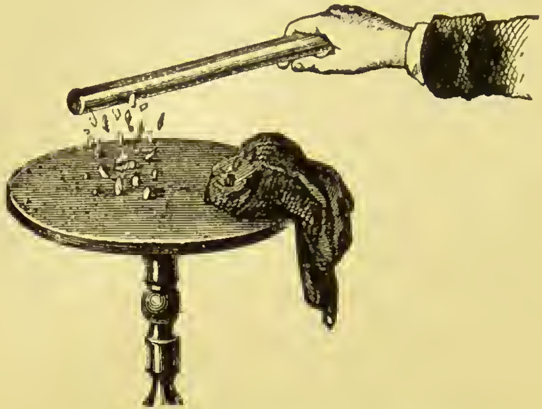

FIG. 139.—Particles attracted by a Rubbed Rod of Glass.

280. **Two Kinds of Electricity.**—It is found that after a substance has been in contact with the excited body, it is repelled by this same body. To show this we may hang a pith-ball by means of a silk thread to a convenient support. On bringing an excited glass rod near this ball it is first attracted to the glass, but after touching it for a moment the glass then repels it. If we now bring near the pith-ball the rod of sealing-wax that has been rubbed with flannel, the pith-ball is seen to be attracted. Light bodies, then, that are repelled by excited glass are attracted by excited sealing-wax, and *vice versâ*, and the glass and the wax are said to be in opposite electrical states. The electricity produced by rubbing glass with silk is called *positive* or *vitreous* electricity, and is represented by the sign +; the electricity produced by rubbing sealing-wax or ebonite with flannel is called *negative* or *resinous* electricity, and is represented by the sign −. From the above experiment we learn that *similarly electrified bodies repel one another, and dissimilarly electrified bodies attract one another.* This may be compared with the mutual action of magnetic poles. The two kinds of electricity are excited by friction between many other substances than those mentioned above, when the bodies differ in qualities of structure and composition. These two sorts of electricity are always produced together and in equal quantities. Thus the silk with which the glass rod was rubbed will be found to possess the opposite kind of electricity to that produced in the glass.

281. **Conductors and Non-conductors.**—When electricity has been produced, it is found to pass along some bodies, as the metals, very easily; while in other cases, as glass and wax, it passes very slowly.

Those substances which allow the electricity to pass easily along are called *conductors*, and those which hinder its passage are called non-conductors.

If the pith-ball were hung by a wire, this would conduct away the electricity, and the ball would not be repelled after contact. The following table gives a few of the bodies remarkable for good or bad conducting powers:—

Conductors.	*Non-conductors.*
Metals.	Ebonite.
Charcoal.	Sealing-wax.
Graphite.	Amber.
Acids.	Caoutchouc.
Saline solutions.	Dry air.
Damp air.	Sulphur.
Flame.	Glass.
Moist bodies.	Silk.

282. **Electrical Induction.**—If a body in a highly positive electric state be brought near a metallic conductor insulated upon a glass support, it will be found that the end nearest the electrified body is negatively electrified, while the other extremity is positively electrified. This is explained by saying that the positive electricity of the substance brought near the insulated conductor attracts the negative electricity towards itself and repels the positive electricity. If we assume, as is sometimes done, two kinds of electric fluid, we may say that the positive electricity of the body brought near the insulated conductor decomposes the neutral fluid of the latter, attracting the negative fluid and repelling the positive fluid. On withdrawing the positively electrified body these two fluids recombine to form a neutral fluid, and the conductor is not then electrified.

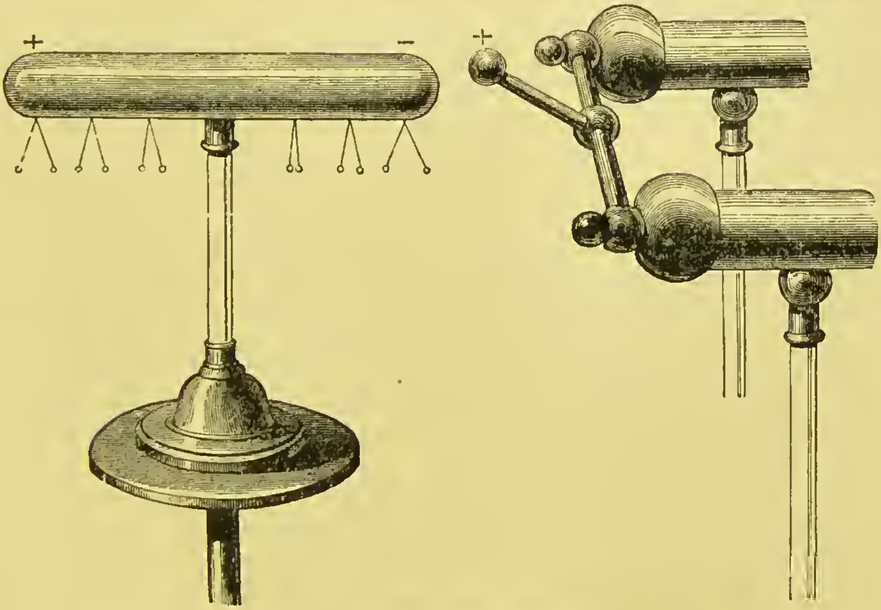

FIG. 140.—Electrical Induction.

The action excited on a substance by an electrified body placed at a distance is said to take place by *influence* or *induction*. If, while our conductor is under the influence of the positively electrified body brought near it, we touch it with the hand at the opposite end, the repelled positive electricity will escape to the earth through our body, and the insulated conductor will then remain charged with negative electricity, even after the exciting body is removed.

283. **Electrical Machines.**—An ordinary electrical machine consists of a circular glass plate which can be turned by means of a glass handle. This plate revolves between two sets of cushions or rubbers of leather. In front of the plate are two brass rods with a series of points opposite the glass, and these rods are fastened to two insulated metal cylinders, which are called the prime conductor of the machine. On turning the circular glass plate electrical separation takes place ; positive electricity appears on the glass, and negative electricity escapes through the rubbers to the earth. The positive electricity of the glass acts by induction on the neutral condition of the prime conductor, attracting the negative electricity to the points, and repelling the positive electricity to the further end of the conductor. In this way the plate abstracts the negative electricity from the prime conductor, and leaves it charged with positive electricity. If the hand or some other conductor be now brought near the prime conductor of the electrical machine a snapping noise is heard, and a bright spark is seen. This disruptive discharge, as it is called, is produced by the sudden union of the positive electricity of the machine and the negative electricity induced in the hand brought near.

284. **Atmospheric Electricity.**—There is always a certain amount of electricity in the atmosphere, though the origin of it is not quite clear. By some it is believed to be produced chiefly by evaporation. Usually the electricity of the atmosphere is positive. When a cloud is charged with positive electricity and comes over a portion of the earth, there is electricity induced of a magnitude equal to the charge of the cloud. The stress thus produced may be so intense as to produce a flash of lightning, and the equal and opposite electricities will disappear. Lightning is therefore a disruptive discharge of electricity between two clouds charged with opposite kinds of electricity, or between a charged cloud and the earth. It is very probable that the aqueous vapour of the atmosphere serves as the carrier of this electricity. The flashes of lightning are often two or three miles in length, and usually proceed in a zigzag line owing to the resistance of the air. When a visible cloud forms from the minute spheres of vapour, the cloud gets denser and denser as thousands of spheres coalesce to form drops. Each of these has its own charge of electricity, and the tension of the droplets is greatly increased As the flash passes, the drops coalesce more easily, and this

may account for the sudden fall of the large drops that so frequently follow a flash.

Several kinds of lightning flashes may be distinguished. 1. The *zigzag* flashes (or *forked* lightning), which move with extreme velocity in the form of a line of fire with sharp outlines, and which closely resemble the spark of an electrical machine. The recent investigation of the shape of lightning discharges by means of extra rapid photographic dry plates, has shown that the path of a discharge is not so sharply zigzag as is usually represented, but has more the shape of the course of a river as shown on a map, and with frequent branchings. 2. The *sheet* flashes, which, instead of being linear, like the preceding, fill the entire horizon without having any distinct shape. This kind, which is most frequent, appears to be produced in the cloud itself, and to illuminate the mass.

'According to Kundt, the numbers of sheet discharges are to the zigzag discharges as 11 : 6 ; and from spectrum observations it would appear that the former are brush discharges between clouds, while the latter are true electrical discharges between the clouds and the earth.

'Another kind, called *heat lightning*, is ascribed to distant lightning flashes which are below the horizon, but illuminate the higher strata of clouds, so that their brightness is visible at great distances : they produce no sound, probably in consequence of the fact of their being so far off that the rolling of thunder cannot reach the ear of the observer. There is, further, the very unusual phenomenon of globe *lightning*, or the flashes which appear in the form of globes of fire. These, which are sometimes visible for as much as ten seconds, descend from the clouds to the earth with such slowness that the eye can follow them. They often rebound on reaching the ground ; at other times they burst and explode with a noise like that of the report of many cannon. No adequate explanation has been given of these.'—*Ganot.*

285. **Return Shock.**—The sudden change of electrical condition brought about when a flash of lightning passes sometimes produces a violent shock even at a distance from the discharge. After a thunder-cloud has discharged its electricity by combination with that of the ground, the surrounding objects that had been acted on inductively suddenly return from the electrical state to a neutral condition, and this abrupt readjustment may produce a concussion which is known as the return shock.

286. **Thunder.**—The peal of thunder which accompanies a flash of lightning is due to the sudden displacement of the air ; and the reverberation of the peal or thunder-roll arises chiefly from the echoes produced by the reflection of the sound from objects on the earth, or from the clouds themselves. The lightning and the thunder occur practically at the same time, but an interval of some seconds is usually noticed between the two phenomena. This is due to the fact that sound travels only at the rate of 1,100 feet per second, while the passage of light is nearly instantaneous. If, therefore, the thunder is heard at an interval of six seconds, the thunder-cloud from which the lightning flash proceeded must be at a distance of 1,100 × 6 = 6,600 feet.[1]

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[1] Thunderstorms are most frequent and violent in tropical regions, while auroræ are phenomena more characteristic of polar regions.

287. **Current or Voltaic Electricity.**—The electricity of which we have spoken hitherto has been produced either directly by friction or indirectly by induction. This kind of electricity is often called static electricity, because it remains on the surface, where it was developed. But electricity can be produced in other ways. It is found that when chemical action takes place electricity is produced. Thus when zinc is being dissolved in dilute sulphuric acid the metal becomes charged with negative electricity, and the liquid with positive electricity. If two plates of dissimilar metals, such as zinc and copper, be placed in a liquid which acts on one of them, a current of electricity will be found to circulate through a wire connecting the plates. The direction of the current in the connecting wire is regarded as passing from the copper to the zinc, which is the direction in which the positive electricity appears to flow through the liquid in the cell. Such an arrangement of two metals in a conducting liquid is called a *voltaic element* or *couple.*

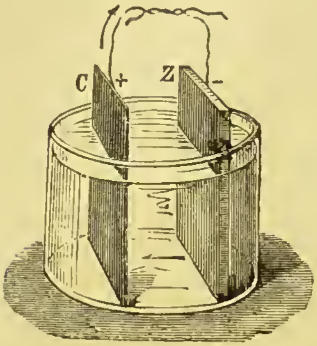

FIG. 141.—A Voltaic Element.

If the wire connecting the two plates of metal be cut, positive electricity tends to accumulate at the end of the wire attached to the copper plate, and negative electricity at the end of the wire attached to the zinc plate. The ends of the wire or terminals are called the *poles* of the battery. A number of voltaic elements or pairs arranged so that the zinc of one element is connected with the copper of another, the zinc of this last with the copper of another and so on, is called a voltaic battery or galvanic battery. Much more powerful effects are produced by the current from a battery than by the current from a single element.

288. **Effects of Current Electricity.**—Wires conveying electricity produce various effects, for the energy of electricity may be transformed into other kinds of energy. If the ends of the wire of a powerful voltaic battery be touched at the same time by the hands a shock is felt. If the poles of a battery be joined by a badly conducting substance like platinum or carbon, *heat* is produced, and with a powerful battery *light* also. Various binary compounds may be decomposed by the electric current. When the poles of a voltaic battery are immersed in water, slightly acidulated with sulphuric acid to increase its conducting power, it is decomposed into its constituent gases, oxygen being given off at the positive pole where the current enters the liquid, and hydrogen at the negative pole (see par. 76). The decomposition of a chemical compound by electricity is called electrolysis (Gr. *luo,* I loosen). The electric current also exerts a peculiar influence over a magnetic needle suspended freely at its centre in a direction parallel to the wire. Such a needle tends to set itself at right angles to the wire—that is, to the direction of the current. Lastly, if a wire conveying an electric current be insulated by surrounding it with silk, and then wound round an iron bar, the latter becomes powerfully magnetic. A bar of iron converted into a magnet by the action of an electric current is called an *electro-magnet.*

289. **Auroras.**—*Auroras, polar lights,* or *streamers* are luminous phenomena often observed in the neighbourhood of

the terrestrial poles. They are most frequently seen in northern latitudes, where the light is known as the Aurora Borealis or northern light. That seen in the Southern Hemisphere is sometimes called the Aurora Australis. There is evidence, however, to show that auroras are manifested in both North and South Hemispheres at the same time. The exact cause of these lights is not known. By some they are believed to be connected with the earth's magnetism, as the auroral corona always forms round the position of the magnetic pole. By others they are attributed to electric discharges which take place in the polar regions between the positive electricity of the atmosphere and the negative electricity of the earth. The appearance may be thus described, though it must be remembered that the forms of the aurora are very varied. Towards evening an indistinct light appears in the horizon in the direction of the magnetic meridian, and this spreads east and west so as to form an arc, with its convex border upwards. Streamers of light then appear and converge towards a point in the sky which is in the direction of the line formed by a prolongation of the dipping needle. The colour of the streaming rays varies, so as some-

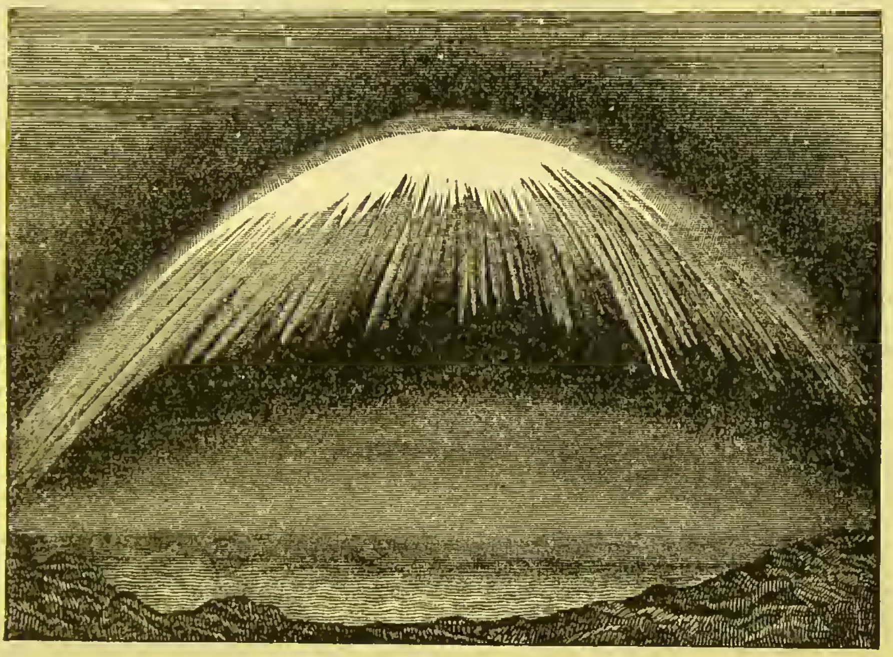

FIG. 142.—Aurora Borealis.

times to produce the appearance of a vast tent expanded in the heavens, the base being red, the middle part green, and the remainder yellow. After some hours the brightness gets less, the colours disappear, and the light vanishes. The varieties of coloured light exhibited by the aurora can be imitated imperfectly by the discharge of electric currents through vessels partially exhausted of air.

The altitude of the aurora varies considerably. Sometimes it takes place at low elevations, but the average height has been estimated at 100 miles. The displays are most frequent in spring and autumn, and least frequent in summer. They may be seen at times as far south as England.

A remarkable connection has been observed between the aurora and the magnetism of the earth, for the magnetic needle is generally disturbed during a display of the aurora. Sudden and great disturbances of the magnetic needle are spoken of as magnetic storms. On November 17 and 18, 1882, a severe magnetic storm passed over the earth, and greatly disturbed telegraphic communication. It was accompanied by a brilliant aurora, and at the same time there were several dark spots forming in the sun. These sun-spots are an indication of outbursts of solar heat. In some places the declination of the magnetic needle varied 1° 81′, and the dip half a degree. The occurrence of the aurora has thus been associated with sun-spots, magnetic storms, and earth-currents. The periods of maximum frequency of these phenomena are at intervals of 11·11 years, and the periods of minimum frequency are about the middle of these intervals.

290.—**Finding the True North and South Line by the Compass.**—The variation of the compass, or the declination of the magnetic needle from the true north and south line, varies in the British Isles from about 16½° W. at the south-east of England to 24° W. at the west of Ireland. There is annually a decrease of this western declination of about 7′. At present, the amount of declination is as follows at certain stations: Dover, 16° 30′; Yarmouth, 16° 45′; London, 17° 12′; Hull, 18° 30′; about 19° at Gloucester, Birmingham, York, and Whitby; about 20° at Swansea and Liverpool; about 21° at Holyhead and Glasgow; Dublin, 21° 30′; Cork, 22°. (See map showing magnetic meridians, in 'Advanced Physiography.') To find the true north-and-south line, *i.e.* the geographical meridian, by means of a magnetic needle, we must draw a line with the help of a graduated circle through the point of suspension of the needle, the requisite number of degrees (according to the declination of the place of observation) to the *east* or right of the line marked out by the magnetic needle when at rest; or the needle must be so placed that it points the declination number of degrees west of the north point of the compass card, when the line joining the north and south points of the card or dial will be the true north-and-south line.

CHAPTER XVI.

THE SHAPE AND MOVEMENTS OF THE EARTH.

291. **Introductory Remarks.**—On looking around us we soon learn that the sun rises every day above the eastern part of the horizon, reaches his highest position in the south at noon, and then declines, to set in the west. Continuing our observations for some time, we may notice that, though the sun is always exactly in the south at noon, he does not rise nor set at one and the same place nor at the same time throughout the year. At night the moon and the stars attract our attention. In the open country we appear to be situated at the centre of an immense hollow globe or sphere, on the inner or concave surface of which the stars and other heavenly bodies appear to lie. With careful watching we may notice some of the stars rise above the eastern part of the horizon, ascend to their highest point in the south, and then descend to disappear below the western horizon. The same stars rise and set exactly at the same points, though not exactly at the same time, day after day throughout the year. Some stars, however, never set, but turn every day in a complete circle above the horizon, round a fixed point of the heavens. If we look towards the north in our latitude, we may at certain times see the stars arranged on that part of the celestial vault in the mode shown in fig. 143, though if the night be very clear and without moon more stars may be seen than are indicated. A careful watch of these stars, continued for some time, will convince us that they are revolving in a direction contrary to the hands of a watch, around a point very near the central star of the figure. This star, around which the others appear to revolve in parallel circles, and which has the same distance above the horizon as the observer's latitude, is known as *Polaris*, or the *Pole Star*. Stars that revolve round it without setting are called *circumpolar stars*. The seven stars seen on the right of the figure are such stars, and form part of a group known as the Great Bear. Two of the stars in this group are known as the 'pointers,' because they indicate the direction in which we

may look for the Pole Star, whether the group is in the position shown in the figure or in any other part of its diurnal circle; for the stars of the Great Bear, always keeping the same position with respect to each other, are among the number of stars which in our latitude are always above the horizon, and, though only visible to the naked eye after the sun's powerful light is withdrawn, they may be seen with a telescope in all parts of their course. We shall return to the diurnal movements of the stars several times.

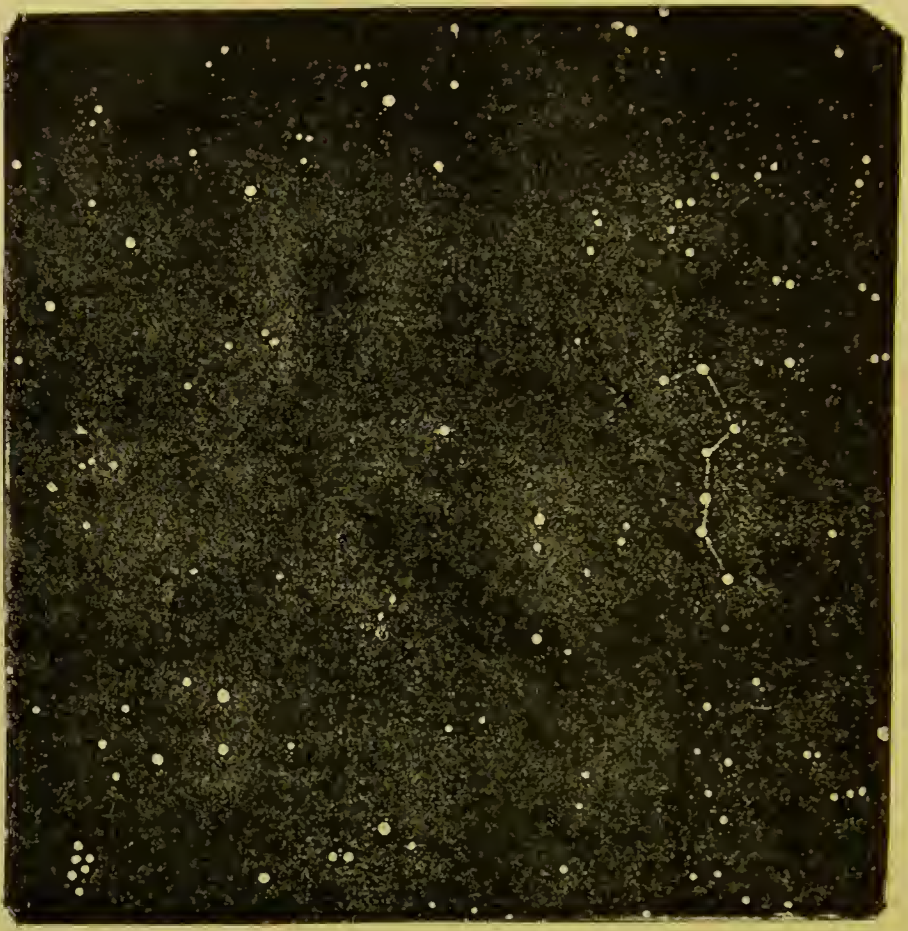

FIG. 143.—The Starry Sphere, looking North. (Great Bear on the right.)

If we wish to point out the *position* of a star on the sphere of the heavens, or the apparent distance of two stars from one another, it is clear that we cannot do this by using our measure of *length.* We cannot say that a star is so many yards or miles from the horizon, or that two stars are so many inches apart. To indicate apparent distance in the sky, we must express the distance in *degrees*, or, in other words, use *angular measure.* Before we explain this we will remind the reader of the meaning of a few common terms.

A *plane*, or plane surface, is a surface on which a straight edge can lie evenly in all directions. It is regarded as having length and breadth, but no thickness. A good floor, the sloping surface of a desk, and the face of a blackboard are all plane surfaces. The position of objects is often described by giving their perpendicular distances from a plane. The intersection of two planes is a straight line.

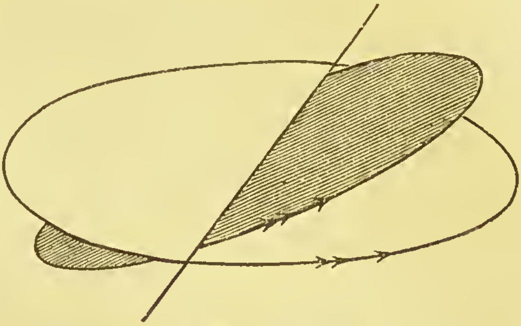

FIG. 144.—Two Intersecting Planes.

A *circle* is a plane figure bounded by one line, which is called the circumference, and is such that all straight lines drawn from its centre (radii) to the circumference are equal.

A *sphere*, or globe, is a round body bounded by a curved surface, every point of which surface is equally distant from the centre. If a section be made by a plane passing through the centre of a sphere, this plane cuts the surface of the sphere in a *great circle.* Any number of great circles may be supposed to be drawn upon a sphere, and all great circles bisect one another. Any section of a sphere made by a plane which does not pass through the centre cuts the surface of a sphere in what is called a *small circle.* Fig. 145 represents a sphere with a great circle E E (seen obliquely as an ellipse)

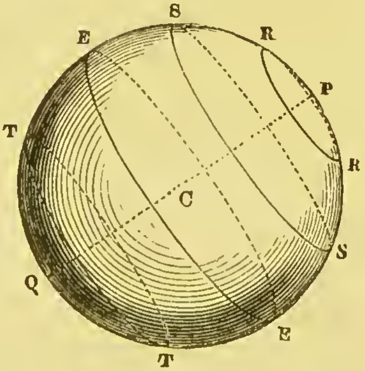

FIG. 145.—Globe, with Great and Small Circles.

made by a plane passing through the centre C; R R, S S, and T T are small circles.

The earth on which we live is a globe, as will shortly be proved, and is often called the *terrestrial sphere.* The *celestial sphere* is that sphere on which all the heavenly bodies, as the sun and stars, appear to be situated. In order to define the position of the heavenly bodies on the inner surface of the celestial sphere, we imagine certain circles traced on its surface, the observer being regarded as situated at its centre. In fig. 146, let the letter O represent the earth, though in reality our earth is but a mere point, so small is it in comparison with the immensity of the celestial sphere. The diameter of the earth about which it turns is called its axis, and when this is produced both ways it meets the celestial sphere in the points P and P′: P is the north pole of the heavens, and P′ is the south pole of

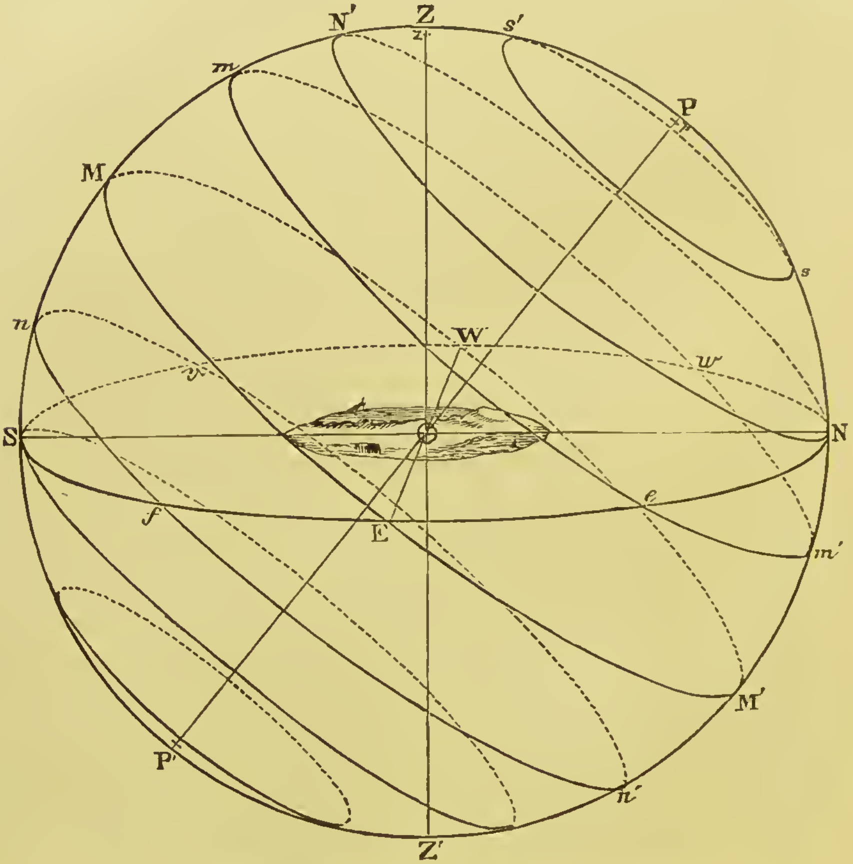

FIG. 146.—The Celestial Sphere at the latitude of London.

the heavens, and the celestial sphere seems, in consequence of the earth's rotation, to turn daily round the axis P P′.

An observer on a level part of the earth sees around him a circular plane bounding his view called the plane of the *visible horizon*. A great circle of the heavens formed by a plane passing through the centre of the earth, and parallel to the plane of the visible horizon, is called the *rational horizon*. At the infinite distance of the heavens these two planes meet and divide the celestial sphere into a visible hemisphere and an invisible hemisphere. The rational horizon is indicated by the great circle E S W N. The central point Z of the visible hemisphere directly over our heads is called the *zenith*, and the central point of the invisible half Z′ is called the *nadir*. The great circle M E M′ W, formed by a plane passing through the centre and perpendicular to the axis, is called the *celestial equator*. It is the plane of the earth's equator extended to meet the heavens, and it intersects the horizon at E and W, the east and west points. The small circles parallel to the equator represent the diurnal paths of the stars. A star rising at E midway between the north and south points ascends in about six hours to its highest point or culmination M on the meridian S Z P N, passes thence in the same time to W, where it sets, to rise again at E on the next day. If a star rises at *f*, its diurnal course above the horizon is smaller, and the time during which it is visible is shorter. It transits the meridian or culminates at *n*. Stars rising anywhere above the horizon on the arc E N culminate somewhere on the meridian between M and N′, remain above the horizon more than twelve hours, and set just as far to the north of the west point as they rose north of the east point. Other stars, whose distances from the pole star are less than the observer's latitude, are circumpolar stars, and perform the whole of their diurnal circles as N N′ and *s s*′ above the horizon.

The stars, whose daily motions we have just been describing are called *fixed stars*, because they keep the same relative position day after day and year after year. Other heavenly bodies that appear like stars to the naked eye, besides rising and setting, move among the fixed stars with a slow erratic motion, and are hence called *planets* (Gr. *planetes*, a wanderer).

292. **Angular Measurement.**—Euclid gives the following definition of a right angle: ‘When a straight line standing on another straight line makes the adjacent angles equal to one another, each of the angles is called a right angle, and the straight line which stands on the other is called a perpendicular to it.’ Notice that ‘perpendicular’ does not always mean upright, but making equal angles on both or all sides. We find it convenient for the purposes of angular measurement to divide the right angle into smaller parts. Each right angle is accordingly divided into 90 equal parts, and each of these parts is called a *degree.* Each degree is again divided into 60 equal parts, one of these parts being termed a *minute;* and if a minute be subdivided into 60 equal parts, each of these parts is termed a *second.* Symbols are used to denote these terms: thus $28^\circ\ 19'\ 47''$ signifies 28 degrees 19 minutes 47 seconds. (Do not confuse these with minutes and seconds of time.) There are four right angles in every complete circle; and so for the convenience of measuring angles we can divide the circumference of a circle into 360 divisions, each of which is called a degree. Such a divided circle is called a *graduated circle*, and the angle whose measurement is so many degrees is the angle included between two straight lines drawn from the centre of the circle to the two marks on the circumference which include the proper number of divisions or degrees.

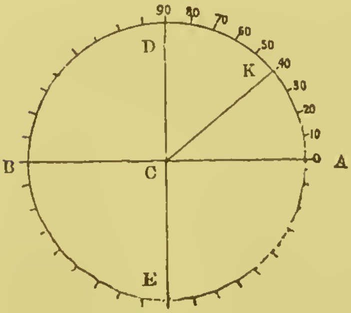

FIG. 147.—Graduated Circle.

It should be noted that a degree is an angle, and not an arc of a circle, though the arcs on a divided circle are often taken as the measure of the number of degrees. For it is shown in geometry that the angles at the centre of a circle are proportional to the arcs on which they stand, and so there are no more degrees in the greatest circle than in the least. Two concentric arcs count as many degrees in the one as in the other when they subtend the same angle at the centre. A degree, then, may be subtended by an arc of any length, but the arc is always the 360th part of a circle. For astronomical purposes the divisions are made to a much greater extent than on an ordinary graduated circle. An instrument called a meridian circle may have its consecutive divisions only 2′ (two minutes) apart, so that the circumference then contains 360 × 30 = 10,800 divisions. The divisions are then read by means of verniers and microscopes. Other mechanical contrivances, which will afterwards be explained, enable astronomers 'to read off,' as it is called, to even the tenth part of a second.

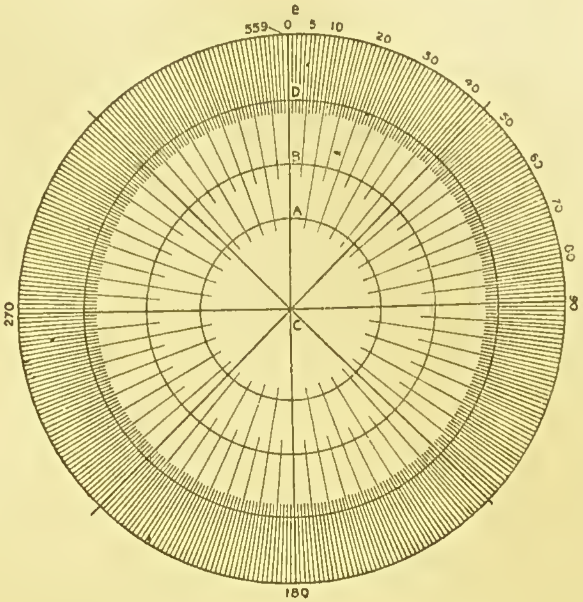

Fig. 148.—Concentric Graduated Circles. The two outer ones divided into degrees.

293. The Use of Angular Measurement in Astronomy.—*Altitude and Azimuth.*—Angular measurement is a very convenient method of indicating the position of the heavenly bodies. The position of a star may be fixed, for example, by referring it to certain imaginary great circles of the heavens, and we may measure its position by arcs perpendicular to such great circles.

(*a*) *First Method of defining the Position of a Heavenly Body.*—In this method the objects are referred to the horizon as the fundamental plane, and in the northern hemisphere the south point of the horizon is the point of origin. Let us draw a diagram to represent the visible portion of the celestial sphere. We can do this by describing a semicircle to represent the observer's meridian. A great circle (seen obliquely as an ellipse) joining the ends of this semicircle will represent the horizon. A point vertically over the observer's head will represent the *zenith*. A point measured off from the north point of the horizon by a distance equal to the latitude of the spectator will mark the position of the north pole of the heavens (fig. 149).

Vertical circles are great circles which pass through the zenith and nadir, and are perpendicular to the horizon.

Parallels of altitude are small circles parallel to the horizon.

The *prime vertical* is the vertical circle that passes through the east and west points of the horizon.

The *celestial meridian* is the great circle passing through the zenith and the poles of the celestial sphere. Its intersection with the horizon marks the north and south points of the horizon, and its plane is perpendicular to the plane of the prime vertical.

The *altitude* of a heavenly body is its elevation above the horizon measured on the arc of the vertical circle passing through the body. It may also be measured by the angle which this arc subtends at the centre of the horizon. (See fig. 149.)

The *zenith distance* of a body is its angular distance from the zenith, and is therefore the complement of the altitude. Altitude + zenith distance = 90°.

As a star approaches the meridian its zenith distance diminishes, and a star attains its greatest altitude on the meridian, when it is said to *culminate.* When a star has reached the meridian one half of its visible path is accomplished, and the passage of a heavenly body over the meridian is called its *transit.* A circumpolar star—*i.e.* one whose whole diurnal circle is above the horizon—has an upper and a lower culmination, and the half sum of these two altitudes gives the latitude of the place.

The *azimuth* of a body is the arc of the horizon intercepted between the south point of the horizon and the foot of the vertical circle passing through the body. It is measured by the number of degrees in the arc of the horizon intercepted between the south point and the foot of the vertical circle passing through the object. In the figure the star R has an altitude of about 55° and an azimuth 45° E. of south. (Sometimes azimuth is reckoned from the south through the west. In this case the azimuth of R would be 315°.) Other stars may be marked on the figure, and their altitude as well as their azimuth or 'bearing' estimated. Stars have the same altitude if on the same parallel of altitude, and the same azimuth if on the same vertical circle. Thus all stars on the parallel of altitude A R T are at the same height above the horizon, and all stars on the vertical arc Z M have the same azimuth. A star on the vertical arc Z W two-thirds above the horizon would have an altitude of 60° and an azimuth of 270° measured eastward from the south.

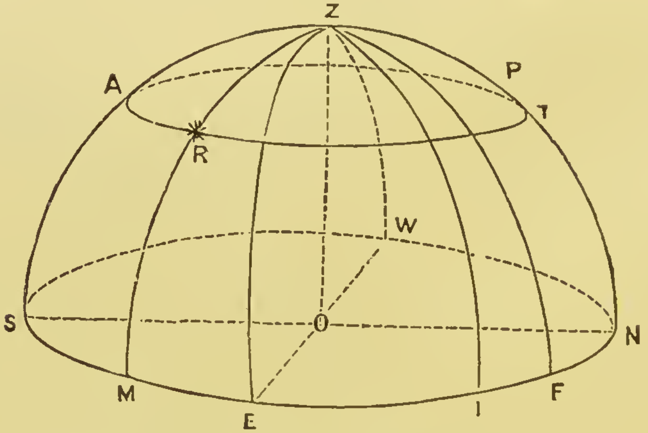

FIG. 149.—The Horizon and Vertical Circles.

O, the observer's position.
Z, the zenith. P, the pole.
S E N W, the horizon.
S Z P N, the meridian.
E Z W, the prime vertical.
M Z, I Z, F Z, arcs of other vertical circles.
R, a star's position.

A R T, a parallel of altitude.
Z R M, arc of star's vertical circle.
Arc S M, or angle S Z M, star's azimuth.
Arc M R, or angle subtended by it at O, star's altitude.
Arc R Z, star's zenith distance.

The *amplitude* of a heavenly body is the angular distance of its rising point from the east and of its setting point from the west, measured along the horizon, or measured by the angle which this arc subtends at the observer's position in the centre of the horizon. The amplitude of the fixed stars remains the same throughout the year, but the sun's amplitude varies during the year. It is nothing at the equinoxes, and about 40° at the solstices for our latitude. Most of the foregoing definitions are illustrated by the figure.

Altitude and azimuth are not often the most suitable ways of indicating the position of a heavenly body, for two reasons: first, because the horizon changes as we change our position on the earth's surface, or, in other words, the 'sphere of observation' varies with change of place; secondly, the position of a star or other heavenly body with reference to the horizon is continually changing at the same place owing to the apparent rotation of the celestial sphere around the horizon. In reality it is the daily rotation of the earth on its axis which causes the horizon to revolve and uncover the fixed stars and the imaginary circles of the celestial sphere, though it is often more simple and convenient to describe the phenomena as if the celestial sphere were rotating and the horizon at rest.

(*b*) *Second Method of defining the Position of a Heavenly Body.—Declination and Right Ascension.*—By referring the places of the heavenly bodies to the celestial equator as the fundamental plane instead of the horizon, we obtain elements independent of the observer's position, and, as far as the fixed stars are concerned, independent of the time (except a very small change to be explained hereafter).

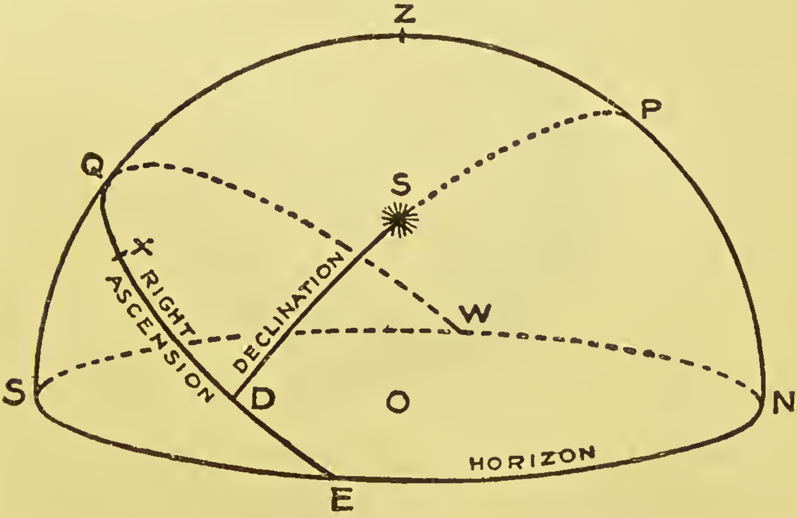

Fig. 150.

E Q W, equator.
S Z P N, meridian.
S E N W, horizon.

Arc S D, declination.
Arc X D, right ascension.
Arc S P, north polar distance.

The *celestial poles* are the points where the earth's axis of rotation, prolonged indefinitely, would meet the celestial sphere. Any line from a point on the earth at any part of its orbit, *parallel to this axis*, vanishes at the same points at the infinite distance of this sphere. The *celestial equator* or *equinoctial* is the great circle of the celestial sphere 90° from each celestial pole. It may also be regarded as the great circle in which the plane of the earth's equator cuts the celestial sphere. At its highest point it is just as far below the zenith as the pole is above the horizon, and it cuts the horizon at the east and west points.

The *declination* of a heavenly body is its distance from the equator measured on the arc of a great circle passing through the body and the pole. It is reckoned positive (+) north of the equator, and negative (−) south of it.

The *polar distance* of a star is the angular distance of the star from the pole measured on the arc of a great circle passing from the pole through the star. Declination + polar distance = 90°.

The *right ascension* of a star is the arc of the equator intercepted between the point where a perpendicular from the star meets the equator and the point called the first point of Aries. In other words, *right ascension* is the angular distance from the first point of Aries. The first point of Aries may here be regarded as the fixed point on the equator where the sun's path, called the *ecliptic*, meets the equator in spring. The opposite point is called the first point of Libra.

The declination and right ascension of a star, unlike the altitude and azimuth, remain the same during the daily rotation of the heavens. Right ascension is always measured eastward all round the equator from 0° to 360°. Fig. 150 shows how to indicate the declination and right ascension of a star. The point Q is found by measuring 90° from P, and the half of the celestial equator above the horizon meets the horizon at the east and west points. A point X is taken to indicate the first point of Aries. The number of degrees in the arc S D perpendicular to the equator measures the *declination* of the star S, and the arc X D measures the *right ascension* of the star. If the reader will draw a quadrant from Z through S, it will meet the horizon perpendicularly, and he will be able to see the altitude and azimuth of the star.

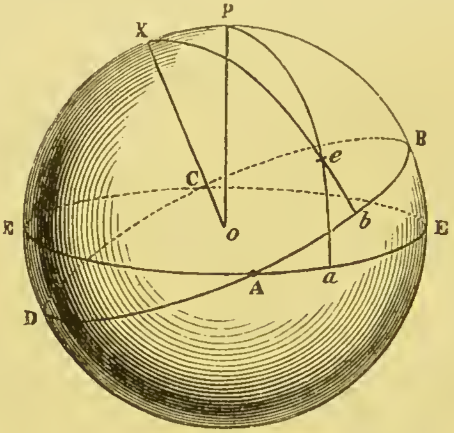

FIG. 151.

o, observer.
A B C D, ecliptic.
A E C E, equator.
K, pole of ecliptic.
P, pole of equator.
A, first point of Aries.
C, first point of Libra.

e, position of a star.
A *a*, right ascension of star.
e a, declination of star.
A *b*, longitude of star.
b e, latitude of star.
Angle B A E, obliquity of ecliptic, or its inclination to the equator.

(*c*) *Third Method of defining the Position of a Heavenly Body.—Celestial Latitude and Longitude.*—This is the method often used in referring to the position of the planets. The student will have noticed already that the terms 'declination' and 'right ascension' correspond to the terms 'latitude' and 'longitude' used in speaking of the position of places on the earth's surface, as in both cases the equator of the sphere in question is the primitive circle by which the above elements are measured. But in speaking of celestial latitude and longitude it must be carefully noted that the ecliptic is the circle of origin.

Celestial latitude is the angular distance of a body from the ecliptic measured on the arc of the great circle passing through the body and the pole of the ecliptic.

Celestial longitude is the arc of the ecliptic between the vernal equinox and the circle of celestial latitude passing through the place of the heavenly body. It is always measured eastward through a whole circumference of 360°.

By help of fig. 151, the meaning of these terms will be better understood, but the reader must notice that the figure is drawn for an observer at the pole, where the equator would also represent his horizon.

The three systems of great circles, with the co-ordinates by which the position of the heavenly bodies are defined, may be thus briefly summarised :—

With regard to the horizon, or the plane perpendicular to a plumb-line—

Altitude = distance from the plane of the horizon.
Azimuth = distance from the south point of the horizon.

With regard to the plane of the equator or plane of earth's rotation—

Declination = distance north or south of the equatorial plane.
Right Ascension = distance from the first point of Aries.

With regard to the plane of the ecliptic or plane of earth's revolution—

Latitude = distance north or south of the plane of the ecliptic.
Longitude = distance from the first point of Aries.

In all these cases distance means angular distance, or distance measured in degrees on the arc of a great circle.

294. **Measurement of Time.**—Round the equator of the earth, which is a circle, there are 360 degrees. We shall find later on that the earth rotates so that the sun reaches its highest point in the heavens once every day for each place on the earth's surface. When the sun is at this highest point it is noon, and the period of time from one noon to the next noon is called a 'solar day.' Now, the length of time from noon to noon is not always the same, varying a little at different parts of the year. But we can take the average of these different days, and we call that average the *mean solar day*. It is used as the unit in all ordinary civil reckoning.

We divide the day into 24 hours, and each hour into 60 minutes, and each minute into 60 seconds. Now, the earth turns round completely, *i.e.* through 360 degrees, in 24 hours, or through 1 degree in 4 minutes.

Of course, we do not actually measure the flight of time by the rotation of the earth, though we see how our unit of time, viz. the day, comes to depend on this rotation. We measure it by means of a clock, the pointers of which indicate the hours of the day, and which is so regulated that an hour marked by it is a twenty-fourth part of the mean solar day.

A clock consists of a means for counting the number of swings or oscillations of a pendulum, and an arrangement for keeping up those oscillations. It serves as a means of measuring a mean solar day and its divisions.

The pendulum consists of a heavy weight C, attached by a string or wire to a fixed point B. The wire hangs motionless in a vertical line until the weight is pulled out to A; on releasing it, it will swing past its former position to A′, and back again. The arc of the swing will gradually diminish, owing to the resistance of the air, unless some means are taken to give the pendulum additional pushes at intervals.

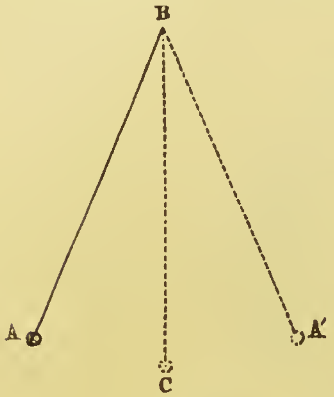

FIG. 152.—Pendulum.

The important principles of the pendulum are—

(1) The time of oscillation is the same with the same length of wire, even when the arc of the swing is made to vary in length.

(2) The time of oscillation is the same with the same length of wire, whatever weight be attached.

(3) The time of oscillation only depends on the length of the wire; the longer the wire is, the longer is the time of oscillation. It is found that a pendulum, the length of which is 39·14 inches from the point of suspension to the middle of the weight, or 'bob,' will swing from left to right in one mean solar second, and back again from right to left in another second.

The pendulum thus serves as an accurate method of measuring time. For convenience the oscillations of a pendulum are made to regulate the movements of the wheels and pointers of a clock. The clock consists of a series of cog-wheels and two pointers, which are made to move round by the descent of a heavy weight. The pendulum locks one of these wheels at each oscillation, and prevents them moving too fast. At the same time this wheel gives the pendulum those small pushes which we said were necessary to keep up its oscillations. Thus there is a compensation: the pendulum keeps the wheels and weights moving uniformly, and the weight keeps up the oscillations of the pendulum. The series of cog-wheels and the two pointers are only a convenient way of indicating the number of oscillations, and thus showing the flight of time.

The annexed figure and description from Ganot's 'Physics' will assist the pupil to understand the above remarks.

'The manner of employing the pendulum is shown in fig. 153. The pendulum rod, passing between the prongs of a fork *a*, communicates its motion to a rod *b*, which oscillates on a horizontal axis *o*. To this axis is fixed a piece *m n*, called an *escapement* or *crutch*, terminated by two projections or *pallets*, which work alternately with the teeth of the *escapement wheel* R. This wheel being acted on by the weight tends to move continuously, let us say, in the direction indicated by the arrow-head. Now, if the pendulum is at rest, the wheel is held at rest by the pallet *m*, and with it the whole of the clockwork and the weight. If, however, the pendulum moves and takes the position shown by the dotted line, *m* is raised, the wheel *escapes* from the confinement in which it was held by the pallet, the weight descends, and causes the wheel to turn until its motion is arrested by the other pallet *n*; which, in consequence of the motion of the pendulum, will be brought into contact with another tooth of the escapement wheel. In this manner the descent of the weight is alternately permitted and arrested, or, in a word, *regulated* by the pendulum. By means of a proper train of wheelwork, the motion of the escapement is communicated to the hands of the clock; consequently their motion also is regulated by the pendulum.'

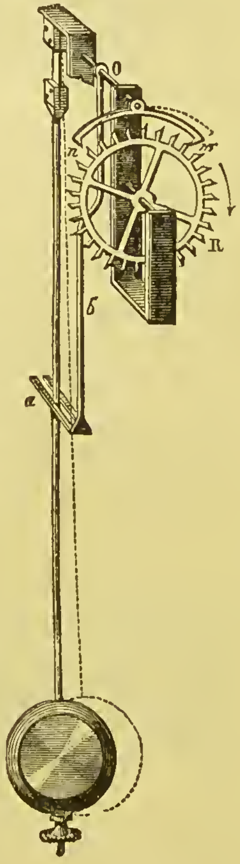

Fig. 153.

In some clocks, and in watches, a spring called the main-spring replaces the weight, and a contrivance called the balance-wheel replaces the pendulum.

295. **The Sundial.**—There is another method of measuring time sometimes used—that by means of a sundial. The essential part of a sundial is a rod on the edge of a piece of metal called a *style*, which is placed parallel to the earth's axis, and casts a shadow on the plate called the *dial*. The plate is marked out with the different hours of the day, and the shadow of the style cast by the sun

passing over it, as the sun moves through the sky, indicates the time of day. As the sun rises in the east, the shadow falls to the west; as the morning progresses, the sun moves to the south, and the shadow to the north,[1] till at noon it is due north, and on the mark indicating XII. In the afternoon the shadow passes eastward. The figure (fig. 155) shows the usual form of a horizontal sundial. This indication of time, depending on the motion of the sun, will not necessarily agree with the indication by a clock; for we have pointed out that the true solar day, or length of time from noon to noon by the sun, is not of constant length at all periods of the year. In fact, the sundial indicates 'true solar time,' the clock indicates 'mean solar time.'

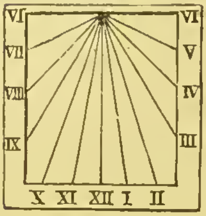

FIG. 154.—Vertical Sundial, facing south.

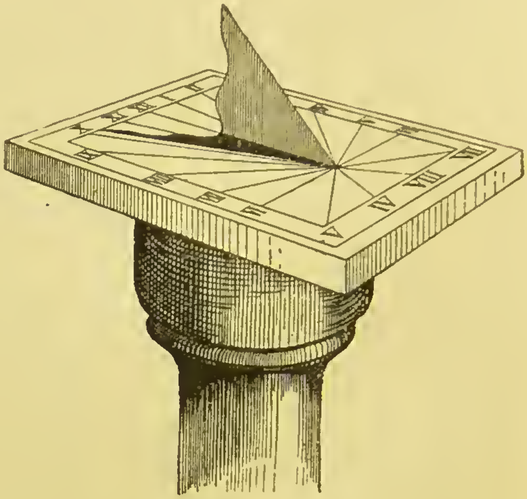

FIG. 155.—Horizontal Sundial, with shadow of style indicating 10.15 a.m.

296. **Size and Shape of the Earth.**—Before discussing the movements of the earth, it will be well to consider the *size and shape of the earth.* The earth is a sphere, or very nearly so. That it is not flat is shown by watching a ship on the surface of the sea, which, in sailing away from the land, disappears as it were behind a hill of water, first the hull sinking out of sight, then the sails, and lastly the very tops of the masts. A

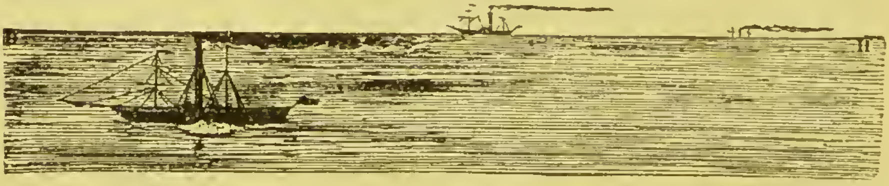

FIG. 156.

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[1] In the Southern Hemisphere south and north must here be interchanged.

further proof that it is not flat is shown by arranging three posts along a level piece of water. The three posts A, B, C, are of the same height above the surface of the water. On

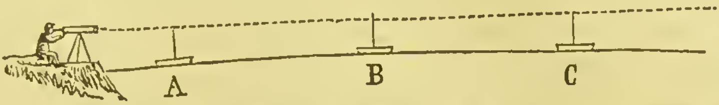

FIG. 157.—Showing how the roundness of the earth can be proved by means of three boats on a large sheet of water.

looking with a telescope so as to see the tops of the posts A and C, the top of the post B will be above the line of sight.

The rise of what we call a great plain, like the level sea, between two observers, or the depression of the surface of the sea from any point, is 8 inches in one mile, 8×2^2 in two miles, 8×3^2 in three miles, and so on for a great distance; *i.e.* the depression is equal to 8 inches multiplied by the square of the number of miles. This can only be true on a globe of a certain size.

That the earth is a sphere is proved by the fact that the horizon, which includes the whole of the earth visible at any one spot, is always a circle wherever the observer may be, and this circle grows larger the higher from the ground the observer may be. A sphere is the only surface which has this property. [This horizon seen from some points may be broken by mountains, and hence not be a circle, but at all spots surrounded by level ground, or by the sea, it is a circle.]

Furthermore, the shadow of the earth cast by the sun on the moon in an eclipse is always round, and again a sphere is the only body which has such a property.

The fact that the earth has often been circumnavigated in various directions also proves that the earth is round, and proves also that the earth is of limited size.

As before remarked, however, it is not quite a perfect sphere, but an ellipsoid or *oblate spheroid*, being somewhat flattened about the poles and having a bulging about the equator (see par. 263). This is *proved* by finding that the length of a degree on a meridian circle of the earth near the pole is a little longer than the length of a degree on the same meridian near the equator. It must therefore be part of a greater circle than the degree near the equator, for the larger the circle the longer is $\frac{1}{360}$ part of it and the flatter is its curve. Further, the increase of the force of gravitation near the poles beyond that due to the decrease of centrifugal force there (par. 18) shows that the earth is slightly flattened at the poles.

Fig. 158 illustrates the shape of the earth, and shows that the earth's surface is less curved near the poles than at the equator. A B subtends the same number of degrees as *a b*, but it is plainly an arc of a larger circle whose centre is at a greater distance. The length of A B is therefore greater than the length of *a b*.

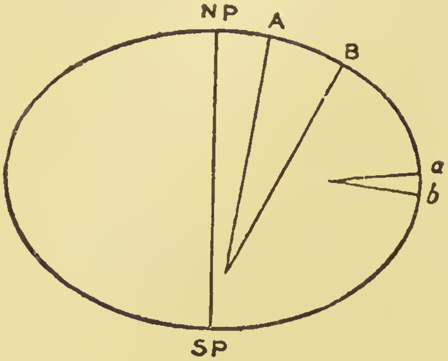

FIG. 158.—Showing that the Earth is flattened at the Poles.

A degree of latitude near the poles is about 69·4 miles, and a degree near the equator is about 68·7 miles, so that an observer must pass over these different distances south or north at these positions to produce a difference of one degree in the altitude of the pole star. If the earth were a true sphere, the length of a degree in all latitudes would be the same. Degrees of *longitude*, being measured between the meridians, are longest at the equator, and diminish rapidly as the meridians approach towards the poles.

Having found by measurement the actual length of a degree on the earth to be about 69 miles, we find the earth's circumference to be 69 × 360 = 24,840 miles. Dividing this result by $3\frac{1}{7}$, we find the diameter to be about 8000 miles. More exactly, the polar diameter is 7899·6 miles, and the equatorial diameter 7926·6 miles—a difference of 27 miles.

297. **Terrestrial Latitude and Longitude.**—To indicate the position of any one spot on the earth, we imagine circles drawn over it, and draw corresponding circles on a globe which represents the earth. The *axis* of the earth is the imaginary line about which we shall find that the earth seems to rotate. The points where this axis cuts the surface are called the *north* and *south poles*. All places equally distant from the two poles are on a great circle called the *equator*. Smaller circles drawn on the globe parallel to the equator are called *parallels of latitude*; and these are drawn on both sides of the equator, being smaller the nearer they are to the poles. They are drawn at equal intervals, and, as on the quadrant of a circle from the equator to the pole there are 90 degrees, these circles are marked off in degrees, the equator being 0°, the next circle being called 10° north latitude, or south latitude, as the case may be, the next 20°, and so on; the last circle being really a point at the pole itself, 90 degrees from the equator. Of course, we might have more circles than are here indicated, as the intervals might be 1 degree or 5 degrees instead of 10 degrees. All places on the same parallel circle have the same latitude.

Other circles are drawn, all of the same size, and all passing through both poles, cutting the equator and all parallels of latitude at right angles. The intervals between these circles are equal at the equator, and are also equal when they cut the parallels of latitude, but the intervals in the latter case are smaller than in the former, as the equatorial circle is larger than any of the other circles of latitude. These new circles are called circles of *longitude*, or *meridians* (L. *meridies*, midday), because when any of these lines is opposite to the sun, it is midday or twelve o'clock at all places situated on that meridian on the same side of the globe, and midnight on the opposite side. They are indicated by degrees; and as there are 360 degrees round the equator, we start from one of the circles of longitude and reckon 180 degrees each way, that is eastward and westward, till we come to the point opposite to that from which we started.

In England we reckon as the first meridian, or 0°, the circle of longitude which passes through Greenwich, and count the longitude eastward and westward from that starting-point. In other countries other first meridians are sometimes taken, though there is now an almost general agreement to adopt that of Greenwich. If, then, we are given the latitude and longitude of a place on the earth, we can easily indicate its position on a sphere.

The degrees of latitude as seen on many maps are drawn at equal intervals, though this is not absolutely correct, owing to the slight flattening at the poles. Hence a degree of latitude may be taken as equal to about 69 miles; for 24,858 miles (the mean circumference) divided by 360 is equal to 69 nearly. The lines of longitude, however, vary in their distance from one another, approaching towards the poles where they meet in a point. Hence a degree of longitude is about 69 miles at the equator only, its length becoming less and less as we get nearer the poles. Thus at London, 51½° N. lat., a degree of longitude is only equal to about 42 miles.

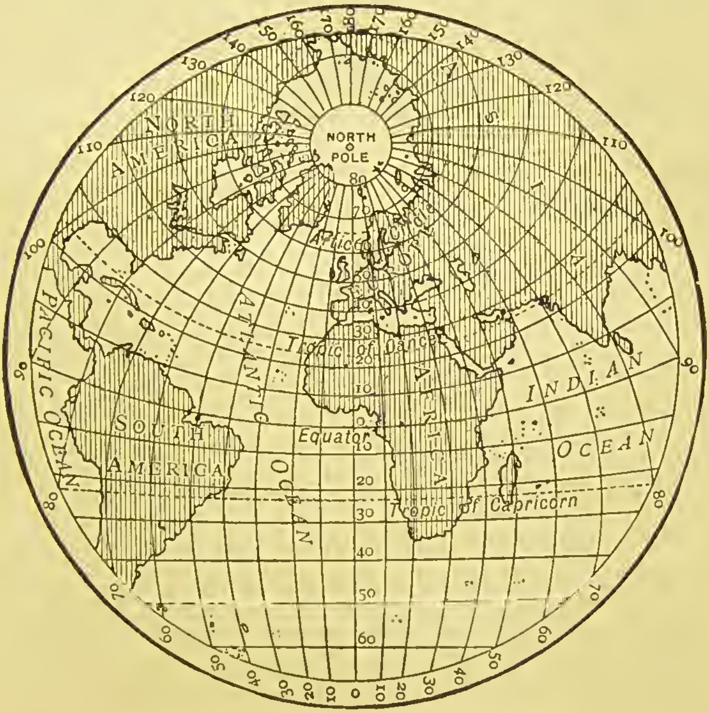

FIG. 159.—Lines of Latitude and Longitude.

We shall presently prove that the phenomena of day and night are the result of the rotation of the earth on its axis. It will thus be plain that places not in the same longitude will not have their noon at the same time. The earth turns completely round, *i.e.* through 360 degrees, in 24 hours, and therefore through 15 degrees in 1 hour, or through 1 degree in 4 minutes. Hence a place 10 degrees east of Greenwich has its noon 40 minutes before

Greenwich, while at a place 10 degrees west of Greenwich it is 11.20 a.m. when it is noon at Greenwich. The pupil will thus see how to find the time of the day at any place in the world, 'local time' as it is called, corresponding to any particular time at another place, having given the longitude of the two places. It is also worthy of note, that as the mean circumference of the earth is 24,858 miles, and as it rotates on its axis once in every twenty-four hours, every place on the equator must be carried round at a rate of more than a thousand miles an hour. As we remove from the equator the circles of latitude become smaller, and their rate of motion proportionally less. Thus at the 60th parallel the rate is only five hundred miles an hour, while at the poles the motion ceases altogether.

298. **The Zones of the Earth.**—Certain parallels of latitude divide the earth's surface into five natural divisions termed *zones*. As will shortly be explained, the position of these dividing parallels of latitude is fixed by the apparent yearly movements of the sun north and south of the celestial equator along the ecliptic. The part of the earth between the parallels of 23½° north and south of the equator (more exactly 23° 27′) is called the Torrid Zone, and the bounding parallels are the Tropic of Cancer on the north side, and the Tropic of Capricorn on the south side. The parallel of 66½° north latitude is called the Arctic Circle. The belt of land round the earth between the Tropic of Cancer and the Arctic Circle is called the North Temperate Zone. The parallel of 66½° south latitude is called the Antarctic Circle, and the belt of land between it and the Tropic of Capricorn is the South Temperate Zone. The regions round the two poles bounded by the arctic and antarctic circles respectively are called the Frigid Zones.

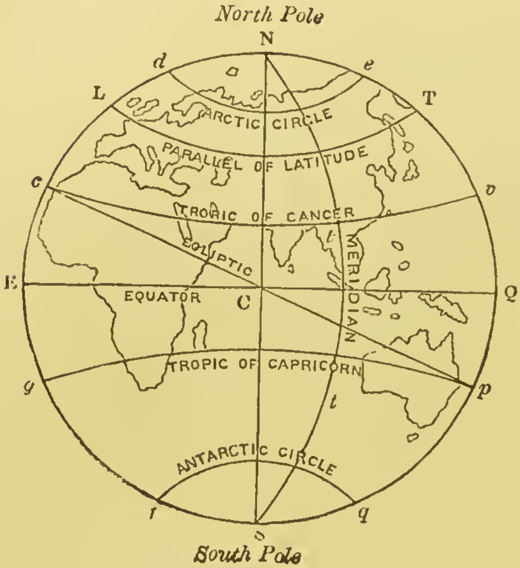

FIG. 160.—Illustrating the Zones into which the Earth is divided.

299. **How a Day is lost or gained in going round the World.**—Travelling westwards, or towards sunset, causes the sun to set later and to rise later, and the day, as measured from one meridian passage of the sun to another, is more than 24 hours long. The local time of the places reached continually gets slower, and the traveller moves the hands of his watch back 1 hour for every 15° of longitude westward. If he were to start from Greenwich and proceed westwards round the earth in a certain number of rotations of the earth he would see one less than this number of noons, and record one day less; *i.e.* he would have made $n - 1$ turns with respect to the sun, while the observer who remained behind had made n turns. Hence on reaching the place from which he started, he appears to have 'lost a day,' being one day of the month behind, though it is really made up of the hours that he put his watch back. Similarly, a traveller going round the world eastward finds the local time continually getting faster,

puts his watch forward, and seems on his return to have 'gained a day.' In order to keep the dates right, therefore, mariners going westward add on a day when crossing the meridian 180° from Greenwich, and drop a day when crossing the same meridian going eastward.

300. **How to find the Meridian of Any Place, and the Cardinal Points.**—The meridian of any place is the line passing from the north pole to the south pole through that place, or it may be described as the line joining the north and south points of the horizon. This line may be found in several ways. By setting up a vertical rod on a plane surface and finding the direction of the shadow at noon when it is shortest, we shall obtain the direction of the meridian or north-and-south line. It is so difficult to settle when the shadow is shortest, that it is best to draw one or more circles round the rod and note the direction of the shadow when the point just reaches a circle before noon, and when it just reaches the same circle after noon. The line bisecting the angle between these two shadows is the meridian line. We might also find the meridian line by drawing a line from a fixed point to the rising sun, and from the same point to the setting sun. The line bisecting this angle would also run north and south. A line at right angles to the meridian would run due east and west, and thus the cardinal points would be determined. We may also fix the meridian by means of the stars. A telescope pointing to any star when at its greatest altitude above the horizon or at the moment of transit, would be pointing along the meridian.[1] A telescope pointing to the pole star, or more accurately the point about which it appears to turn, would be pointing in the plane of the meridian, and the north point of the horizon is vertically beneath the pole in north latitude. We can also find the

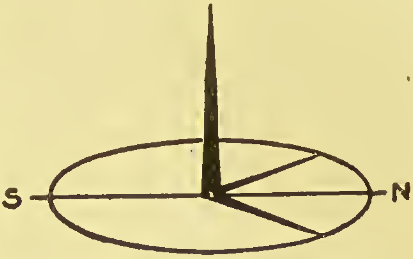

FIG. 161.—Method of finding the Meridian.

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[1] A more accurate result will be obtained if a star be observed by means of a suitable telescope when it is at the same altitude east and west of the meridian, for the mean of the two readings of the azimuth circle will give the exact direction of the meridian.

geographical meridian by means of a mariner's compass if we know the declination or variation of the needle at the place of observation (see par. 290).

301. Apparent Daily Rotation of the Heavenly Bodies.—Our earth is a globe situated in celestial space and surrounded by other globes at various distances from it. We have already mentioned how the celestial sphere seems to rotate each day, causing the sun, moon, and some of the stars to rise and set. Thus the sun rises daily above the eastern part of the horizon, ascends slowly to its highest elevation, and then slowly descends along the same arc to sink in the west. When

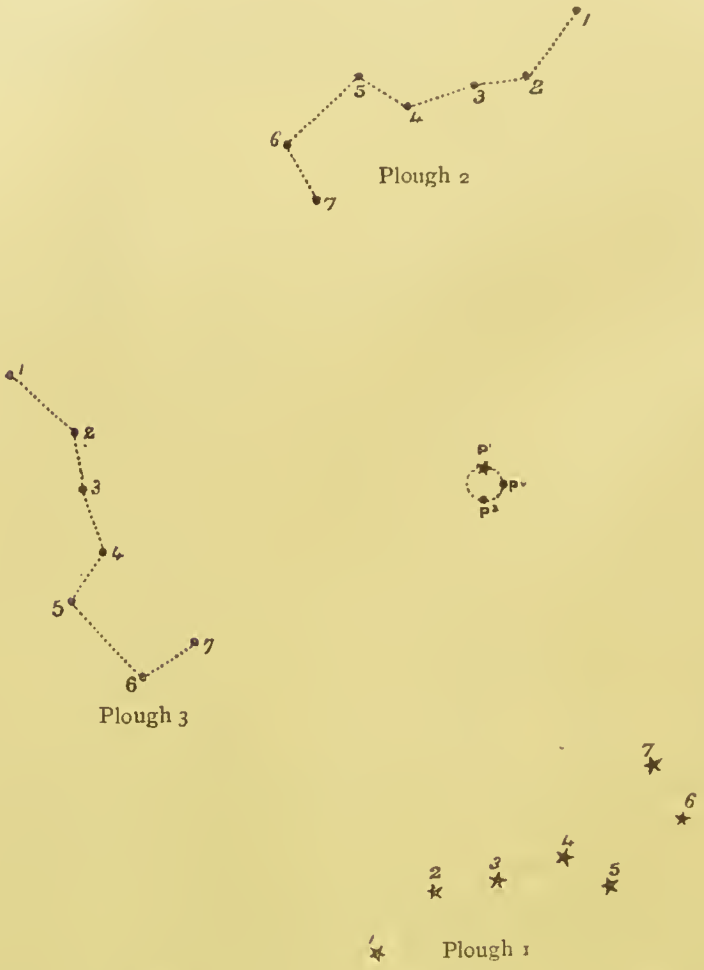

FIG. 162.—Three positions of the Plough (Great Bear) and the Pole Star in their daily revolution round the Pole.

at its highest point it is noon, and the centre of the sun is exactly over the meridian of the place of observation. We say, therefore, that the sun crosses or *transits* the meridian when at its greatest altitude each day. It is evident that different places on the earth's surface may be on the same meridian and have their noon at the same time, but it can never be noon on two meridians at the same time. The time between two successive passages of the sun across a meridian is called a *solar day*, and is equal to about 24 hours of clock time. We say 'about' 24 hours of clock time, because, as will shortly be shown, the true solar day, or actual interval of time between two meridian passages of the sun, is not of the same length at all parts of the year, and it is the average of the different solar days in a year, or 'the mean solar day,' which is exactly 24 hours of clock time. The diurnal paths of the stars have been already referred to (see par. 291). Looking towards the pole star, which can always be found on a clear night by the pointers of the Great Bear, or Plough, as its seven stars are also called, we find the stars describing daily circles of various sizes round the pole of the heavens, and a first examination may therefore lead us to suppose that the various celestial bodies external to the earth perform a daily revolution from east to west around a line or axis terminating at the pole star, all completing their revolution in the same time. But this is really not the case, for there is a more satisfactory explanation. The earth, in fact, rotates daily on an axis, carrying with it the atmosphere and clouds, which are indeed a part of it.

302. **Rotation of the Earth on its Axis.**—Let us consider what happens when we are in motion in a railway train, or on a steamboat. If we look out of the window, the trees, telegraph poles, and all bodies external to the train, which we know to be stationary, appear to be in rapid motion in a direction contrary to our motion. The deception is greater if the train or steamboat moves very smoothly, without any jerks or jolting. Indeed, with a very smooth motion we might think that we are stationary, and all outside objects are moving rapidly past us; but on closer investigation we should really find that outside objects were stationary, while we were

moving rapidly in an opposite direction to that in which we thought the objects were moving.

Now let us apply this, on a larger scale, to the whole earth and bodies external to it. The daily motions of sun, moon, and stars are explainable by supposing that we and the earth on which we stand are stationary, while those bodies move uniformly round us. But these apparent motions are equally explainable by supposing that these bodies are fixed in different positions round the earth, and the earth rotates round in a direction opposite to that in which they seem to move, *i.e.* the earth must turn from west to east, for they seem to move from east to west. This rotation of the earth would account for the rising in succession of the sun, moon, and the different stars, which follow one another to the west, and disappear, only to reappear in the same manner on the succeeding day. Everything on the earth moves with it, and moves smoothly, and thus the motion is not evident to our senses. Are we, then, to suppose that these heavenly bodies move round the earth, or that the earth rotating itself gives them an apparent motion? We have very good reasons for supposing that it is the earth which rotates, and thus gives us the daily rising and setting of these external bodies. The reasons are—

(i.) All of these bodies are very distant from the earth, the stars especially being very far distant, so that they would have to move at an immensely rapid pace to get round the earth in one day, as they seem to do; while on the contrary, it would be at a comparatively slow pace that the earth would have to move round on its own axis so as to make one complete turn in the single day. The external bodies are then considered to be stationary. It seems more reasonable that the earth turns thus slowly than that they move at such an immense pace.

(ii.) All these external bodies appear to move round us in exactly the same time—one day, or twenty-four hours. If we consider how they are scattered over all the different parts of the heavens, and at different distances from the earth, we should not expect all to move round us in the same time, unless indeed they were connected by some means, such as rods and bars, with one another. We see no signs of any such connections, however, between these different bodies. If we suppose that the earth rotates whilst they are stationary, then at once we see that they will appear to move in a direction opposite to that in which the earth rotates, and that they will appear to follow one another at a uniform rate, and will accomplish the journey in exactly the same time, viz. one day, which is the time the earth takes to perform one rotation, so that there is no need of any connecting rod.

(iii.) We find, on careful measurement, that the earth is not exactly a sphere, but that it is slightly flattened at the poles and bulges somewhat at the equator. Thus a straight line through its centre from pole to pole is about 27 miles shorter than a straight line through its centre at right angles to the first straight line. Geologists tell us that the earth was once soft and plastic, and if this were so, it has been calculated that a rotation about its axis would have caused it to assume the shape which it now has. Thus a rotation of the earth about its own axis will explain its present shape. (See par. 263.)

(iv.) If we observe those external bodies called the planets, we find, by means of our telescopes, that each of them is a globe revolving around its own axis. Hence it seems very probable that the earth, which is a similar globe, will also revolve about its own axis.

The above are only reasons for believing that the earth rotates about its axis, but there are other evidences which amount to actual proofs.

1*st Proof.*—The top of a tower is farther from the centre of the earth than the bottom is, and hence in one rotation of the earth moves through a greater distance than the bottom does. Thus in fig. 136, where T B is supposed to represent the tower, it is evident that in a revolution the top T will describe a larger circle than the base B, and so travel a greater distance. Now, as the top completes its revolution in the same time as the bottom, it is evident that it must move faster than the bottom. We suppose that the earth rotates from west to east, and, if this be so, the top of the tower moves eastwards faster than the bottom does. Thus if a stone be dropped from the top of a vertical tower it starts with an eastward velocity greater than that of the bottom of the tower, and as in its fall it preserves its greater velocity it should fall a little to the east of the bottom. This experiment was performed at Hamburg from the height of 250 feet, and the deviation was found to be ·35 inch to the *east*. Hence we conclude that there must be a revolution of the earth *from west to east*. Let C (fig. 136) be the centre of the earth, T the place from which the body is let fall, T B the vertical line in direction of the centre. When the body reaches the earth, let *t b* be the position of the vertical line in consequence of the earth's motion in the interval. Take B *f* = T *t*, and *f* will be the place of the body, because the body, leaving the top of the vertical with a motion equal to the motion of the top, is, at the end of its fall, as far from the first position of the bottom of the vertical as the top of the vertical itself is from its first position. But B *b* is less than T *t*, and therefore than B *f*, in the proportion of C B to C T; consequently *f* is to the eastward of *b*. This is on the supposition that the place is at the earth's equator, and it may suffice for an illustration.[1]

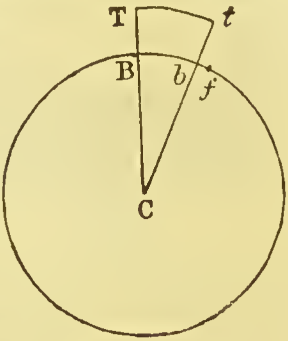

Fig. 163.

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[1] To find the exact time of the earth's axial rotation, we only require to determine the length of the sidereal day by finding the interval between two successive transits of the same star. Astronomers do this with the aid of a transit telescope, which is so mounted as only to move up and down in the meridian of the place where it is used. (See par. 322.) If an observer having an accurate watch, fix two strings or wires vertically at a short distance apart, and then, keeping them both in line of sight, watch the same star cross them on two successive nights, he will find the time of the earth's rotation to be about 23 hours 56 minutes.

2nd Proof.—We take a long thread; fixing one end to the ceiling of a room or other convenient point of attachment, and fastening a heavy weight to the other, we form a pendulum. The string remains at first in a vertical direction. Now place a table under it and draw the weight towards you, and then let it go, so that it swings backwards and forwards through its former position. Care has to be taken at starting not to pull the weight sideways, or it will not swing back through its former position.

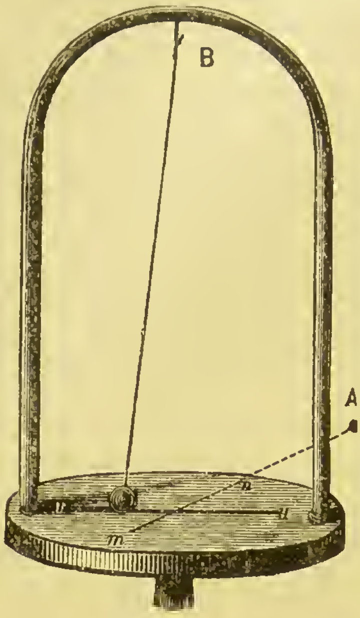

FIG. 164.

On the table mark the farthest position to which the weight swings at each end of its journey. We shall find that our marks on the table are slowly and regularly going round in the same direction as the hands of a watch. Hence the table must be moving, and therefore the earth is also moving. For it is easier for the thread or wire which supports the pendulum to twist than for the heavy weight to alter its course of swing.

The figure shows how this experiment may be carried out. B is the point of suspension of the pendulum, which hangs vertically over the point where the two lines *m-n*, *u-v* cross on the table. The pendulum is drawn out along the line *m-n* to the point A, and then let go, swinging backwards along the line *n-m*. It continues its oscillation backwards and forwards, but if watched it will be found that the direction of its oscillation is slowly twisting round from the position *n-m* to *u-v*—in fact, twisting round in the direction of the hands of a watch in the Northern Hemisphere, and in the opposite direction in the Southern Hemisphere. If the oscillation is kept up long enough, the plane of oscillation will make a complete circle. Now, it can be proved that a pendulum having a free motion at its pivot, when set swinging, keeps its direction in space, whatever change of position its support may undergo. Its change of path over the floor or table above which it swings must therefore be due to the rotation of the earth with the objects upon it beneath the pendulum. The fact that the plane of oscillation turns towards the right in the Northern Hemisphere, and in the reverse direction in the Southern, shows that the earth rotates from west to east. This experiment was first performed by Foucault, who swung a pendulum from the dome of the Pantheon at Paris in 1851. The rate of change in the direction of the plane of oscillation of a swinging pendulum decreases from the pole to the equator. At the pole it amounts to a complete circle in 24 hours, or 15° in one hour; at London it is a little over 11° in an hour; at Cairo about 8°; and at the Equator 0°.

3rd Proof.—A gyroscope consists of a heavy disk which has an axis passing at right angles through its centre, and by a mechanical contrivance the axis can easily turn in all directions. The figure (fig. 166) shows one form of gyroscope. A B is the heavy disk rotating about the axis C D, the axis being supported by a rim of metal, which again can turn round the axis E F, this last axis being supported by another rim of metal, which can turn round as it hangs by the string H G. Therefore the axis C D is

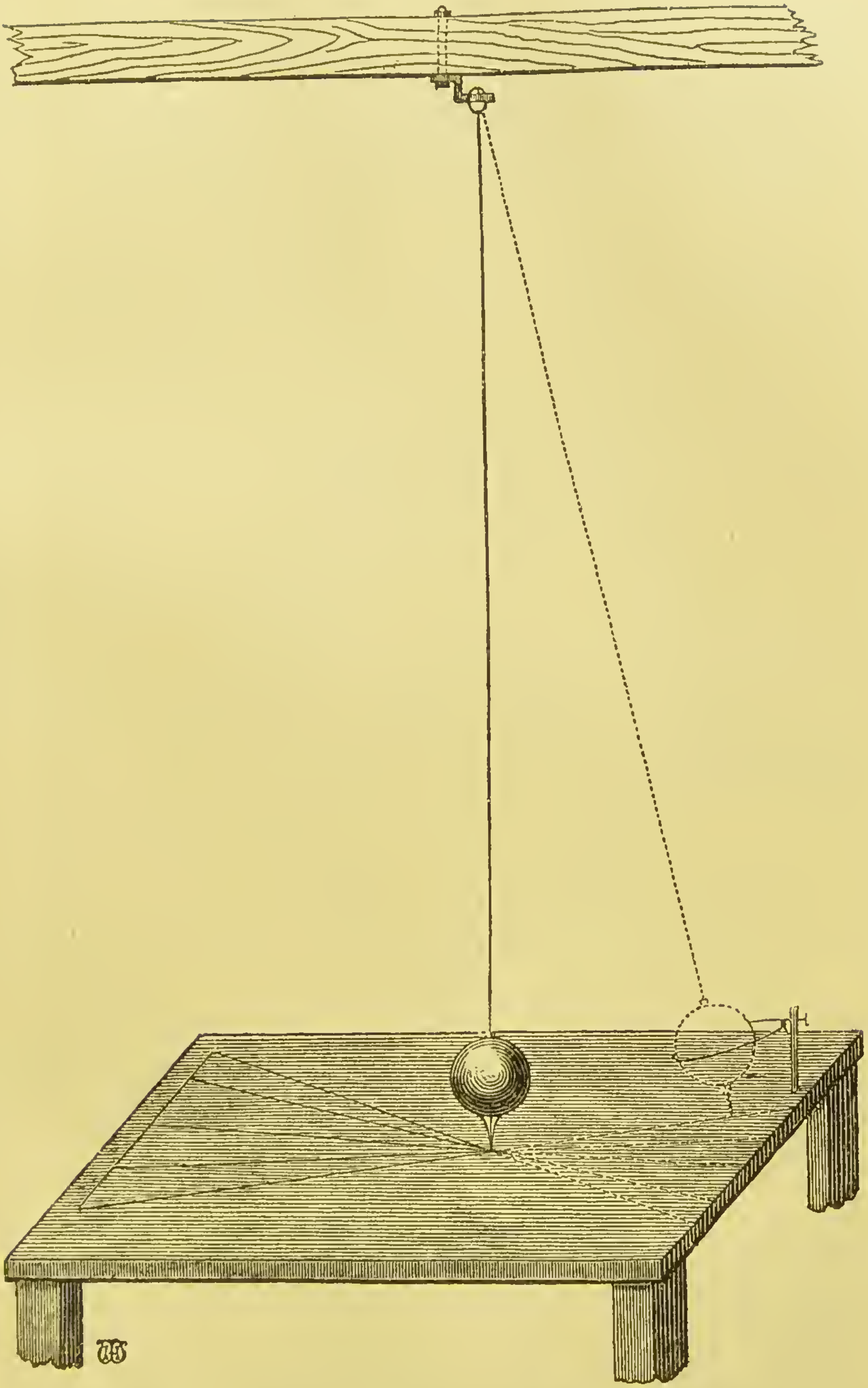

FIG. 165.—Foucault's experiment in Northern Hemisphere, proving the rotation of the earth from west to east by the apparent deviation of the plane of oscillation of a pendulum towards the right.

free to turn in all directions. The disk is set spinning very rapidly, and will continue to spin for a long time. It can be proved that the axis will always point in one direction when the disk so spins. Imagine, then, the disk spinning, and the axis pointed to any star. If the star moves round the earth the axis will soon point away from the star, and will keep the same position with regard to the bodies on the earth. But if the star is motionless, and the earth rotates, the axis will still point to the star, following it, as it were, and thus, of course, pointing in different directions with regard to surrounding objects on the earth. We find the latter happens ; the axis points continually to the star, and therefore the earth rotates.

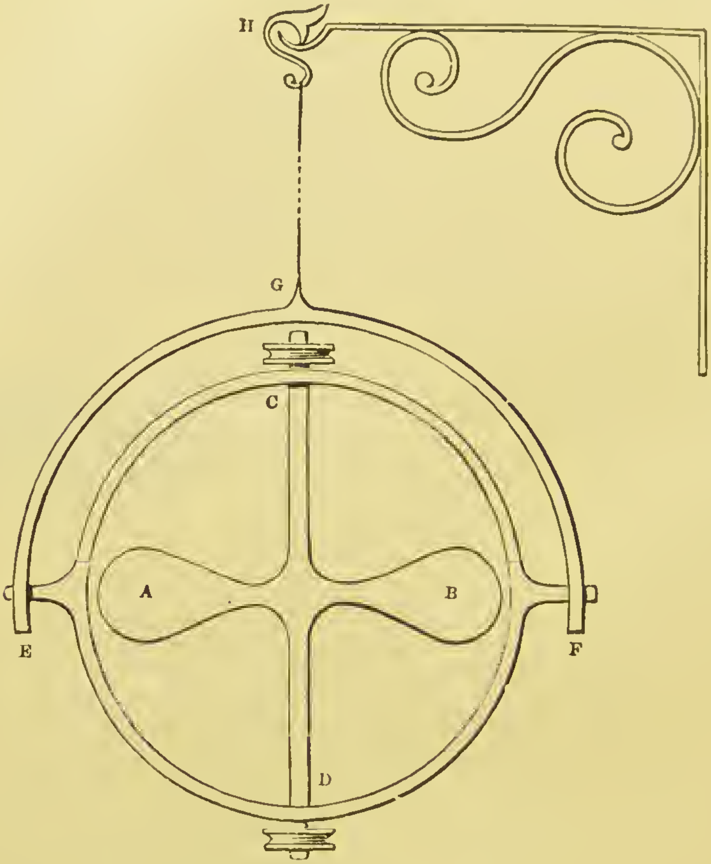

FIG. 166.—Gyroscope.

4th *Proof*.—The easterly direction of the trade winds can only be explained by supposing that the earth rotates from west to east. The currents of air passing towards the hotter parts of the earth undergo, in consequence of the earth's rotation, a deviation towards the right in the Northern Hemisphere, and towards the left in the Southern, so that winds from the north become north-east winds, and winds from the south become south-east winds. A deviation in certain ocean currents is also explained by the earth's rotation.

We have thus sufficiently proved that the earth rotates on its axis once a day, and that this diurnal rotation gives us the daily risings and settings of the sun, moon, and stars—causing, in fact, the celestial sphere to revolve round an imaginary axis, which is the axis of the earth produced to the sphere of the heavens. One effect of this daily rotation of the earth is that the earth will evidently turn first one half and then another towards the sun, and we get the ever-recurring phenomena of day and night. We will now, however, consider more particularly this rotation as far as it affects the motions of the stars at different distances from the poles.

303. **Daily Appearances of the Stars in Different Latitudes.**—Each place on the earth has its sphere of observation, with its own zenith and horizon. Imagine an observer at the north pole of the earth. Then the zenith or point straight overhead and the north pole of the heavens will coincide, and the true or rational horizon will coincide with the celestial equator. The heavens will appear to revolve round the zenith, each star describing a circle parallel to the horizon. These parallel circles increase in size as we pass from the pole to the equator. No star on this 'parallel sphere' rises higher or sinks lower, and an object upon the equator will perform its diurnal motion round the horizon. One half of the heavens will be continuously visible, turning round once each day, and the other half below the horizon will never be visible.

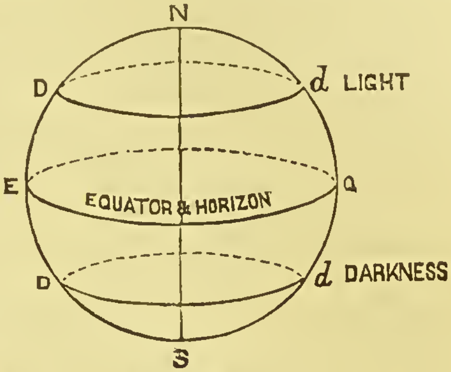

FIG. 167.—Parallel Sphere, with Pole at Zenith, and Celestial Equator for Horizon.

Let us consider the appearances to an observer on the equator (fig. 168). C is the observer; N and S the points on the horizon respectively north and south. E is his zenith. The celestial equator is the circle passing through E Q, being, of course, vertical to his horizon, and perpendicular to N S, which is parallel to the earth's axis. The heavens seem to revolve about this axis N S, and thus stars rise on all parts of the eastern horizon, describe circles parallel to the equator, and set in the west. Every star rises in some part of the day, and sets twelve hours later, describing a semicircle above the horizon, these semicircles getting smaller and smaller the farther the star is to the north or south.

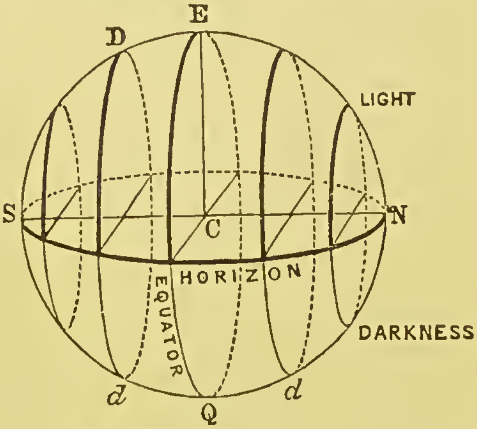

FIG. 168.—Right Sphere: Poles on Horizon.

Let us now consider the appearances to an observer who is between the equator and the north pole (fig. 169). The celestial sphere has this appearance. N is the north pole; E Q the circle of the equator, intersecting the horizon obliquely, H O being the horizon. The heavens appear to revolve about an axis passing through the centre of the sphere and through N, this being at right angles to the equator. All stars appear to describe circles, like *d* D, parallel to the equator. It will be noticed that the stars to the north of the equator are above the horizon for the greater part of their path, below it for the smaller part. On the southern side of the equator the reverse is the case; they will be above it for the smaller part, below it for the greater part. A star above O will describe a path, like *pp′*, such that it is never below the horizon, thus never rising nor setting. These stars are called *circumpolar stars.* Stars below H never appear above the horizon, and so are never seen. The greater part of the heavens are visible at some time of a complete day, the parts below H being the only parts never above the horizon. These parts are, of course, just equal in extent to the parts above O, that is, the parts in which are the circumpolar stars which never set. We get similar appearances at different positions in both the Northern and Southern Hemispheres, the only difference being that the nearer we go to the equator the lower the celestial pole is, and consequently the fewer circumpolar stars there are, and the fewer stars which are never visible.

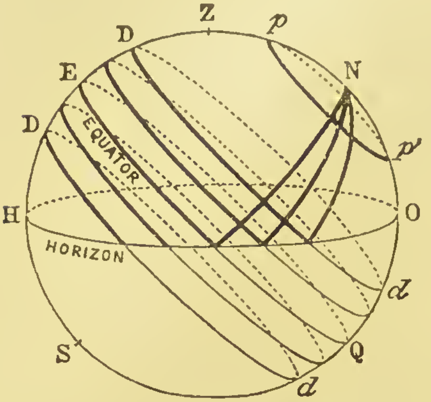

Fig. 169.—Oblique Sphere at Mid-latitude.

In fact, the celestial equator is inclined to the horizon, at all latitudes between the equator and the pole, at an angle equal to the distance of the poles from the zenith. Fig. 169 is drawn for latitude 45° N., and fig. 146 is drawn for the latitude of London, 51½° N.

The appearances of the stars, then, owing to the daily rotation of the earth, are different at different parts of the earth.

(1) At the poles stars never rise or set, and the same half of the heavens is continuously visible.

(2) At the equator all stars rise and set, and in one complete day the whole heavens have been visible.

(3) Between the poles and the equator we have stars which rise and set, circumpolar stars that never set, and stars which never rise, the parts of the heavens in which these last are being the only parts never visible.

The number of circumpolar stars, and of those that never rise, increases as we take positions further from the equator towards either pole of the earth.

The student should practise drawing a diagram of the celestial sphere for any latitude, and then indicate upon it the diurnal path of stars having a given declination or distance from the equator. To do this, draw a complete circle to represent the meridian of the celestial sphere, the observer being at the centre of this sphere. A horizontal great circle (shown as a flat ellipse) bisecting the meridian will represent the rational horizon. The horizon meets the meridian at the north and south points, and divides the celestial sphere into a visible half and an invisible half. The zenith will be 90° above any point on the horizon, that is 90° from the north or south points, and the nadir will be 90° below the horizon. Remembering that the elevation of the pole is equal to the latitude of the place of observation, find a point as many degrees above the *north* point of the horizon as the observer's latitude, and this will give the north pole of the heavens. The south pole of the heavens will be just as far below the southern point of the horizon as the north pole is above the north point of the horizon. To obtain the celestial equator, draw a great circle 90° from the poles, dotting the half on the west side of the horizon. The points where the celestial equator cuts the horizon are the east and west points (see fig. 146). To draw the diurnal path of a star whose declination is 30° N., draw a circle parallel to the equator at this distance above the equator, and the required path is obtained. To draw the diurnal path of a star with declination 75° N., we require a parallel circle at this distance north of the equator. For a star with declination 60° S., we require a circle parallel to the equator at this distance south of it. Where the diurnal circles of the stars meet the horizon indicates their rising and setting points. The angular distance of the rising point of a star from the east gives the *amplitude* of the rising star, while the distance of its setting point from the west gives the amplitude of the star at setting. If a star's diurnal circle does not intersect the horizon, it is the diurnal circle of a circumpolar star if its declination is north ; it is the diurnal circle of a star that is never seen north of the equator, if its declination is south.

Fig. 146 is drawn for the latitude of London, $51\frac{1}{2}$° N. M M′ is the celestial equator, and a star or other heavenly body on the equator has declination 0°. It rises exactly in the east, and sets exactly in the west. A star rising at *e* between the east and north has a declination, the arc M *m*, of about $23\frac{1}{2}$°, and is carried to its highest point at *m* on the meridian, and then descends to set at *w*, between the west and north. More than half its diurnal circle is above the horizon. The stars rising at N and *s* are circumpolar stars, describing the whole of their diurnal circles above the horizon. They culminate or reach their highest point on the meridian at N′ and *s*′ respectively. The arc M N′ is about 40°, and this gives the north declination of the star whose path is the circle N N′. What is the north declination of the star whose path is represented by *s s*′? The star rising at *f* culminates on the meridian at *n* and sets at *v*, only a small part of its diurnal circle being above the horizon. What is the south declination of this star? The paths of two other stars that are never visible in the Northern Hemisphere are shown. Find the south declination of each.

From our study of the paths of the stars, we can add to the numbered statements already made the following :—

(4) At all latitudes in the Northern Hemisphere between the poles and the equator, the stars whose distances from the north pole are less than the latitude of the place are circumpolar stars, the stars whose distances from the opposite pole are less than the latitude of the place never become visible, while stars included between these limits rise and set. The daily courses across the heavens of the stars that rise and set are greater or less than 12 hours, according as they have north or south declination, for it must be remembered that the daily courses of all stars, however great or small their diurnal circles, are accomplished in the same time, viz. 24 hours.

304. **Yearly Changes in the Appearance of the Sun.**—*Revolution of the Earth.*—Besides the daily rotation of the earth and its effects in producing an apparent daily motion of the sun and stars, we will consider another apparent motion of the sun. If we observe, for many nights in succession, the stars which first appear on the horizon in the west after sunset, we shall find them to be slowly and continually changed. Those stars which we first saw on the horizon after sunset will be found to have set before the sun, and other stars will be on the horizon which formerly appeared higher up in the heavens. If we observe the east also we shall find that those stars which we saw first on the horizon at the beginning

of our observations are higher in the heavens when they have become visible after sunset. The longer we continue our observations the higher will the last-mentioned stars appear, and in the course of some months the first-mentioned stars, which have set in the west before sunset, will reappear in the east after sunset. These effects can be explained by supposing that the sun has a motion from west to east round the heavens, passing over the stars. This motion is quite independent of the daily motions which affect the sun and stars alike. It is a slow motion—in fact, we should have to watch a whole year to see one revolution completed. Thus we have an apparent motion of the sun round the heavens in one year's time. However, we remember that there was an apparent daily motion of the sun round the earth from east to west, which was found to be not a motion of the sun, but a daily revolution of the earth from west to east, which gave an apparent motion to the sun in the opposite direction, viz. from east to west. Is this yearly motion of the sun real, or only an apparent motion of the sun due to some rotation of the earth? To answer this we must see if there is any possible motion of the earth which would give us such an apparent yearly motion for the sun. We remember that it has a daily revolution on its axis from west to east, which made the sun seem to revolve daily from east to west; it could not have also a yearly revolution on its axis which could give this fresh yearly motion to the sun. But instead of the sun moving round the earth in a year, the earth could move round the sun in a year. We must see if this supposed motion of the earth would explain the apparent motion of the sun. But we must remember that it is a yearly motion, quite independent of the daily revolution of the earth, and for the present we may leave out of consideration the daily motion. We will first take the supposition that the sun moves round the earth from west to east amongst the stars.

Let S represent one position of the sun, E the position of the earth, A, B, C, D, stars beyond and behind the sun. (These stars would not be visible in the sunlight, but we know they must be there, for we can see them at another part of the year when the sun is not in that part of the sky.)

When the sun is at S it appears in front of the star we call C; in a few days it seems to move eastward to S′, when it is in front of the star D, and then seems to continue in its eastward motion till finally in a year's time it has again come round to the position S. But this apparent motion of the sun is equally explained by supposing the sun fixed at S, and the earth to move from E in the opposite direction—*i.e.* westward.[1]

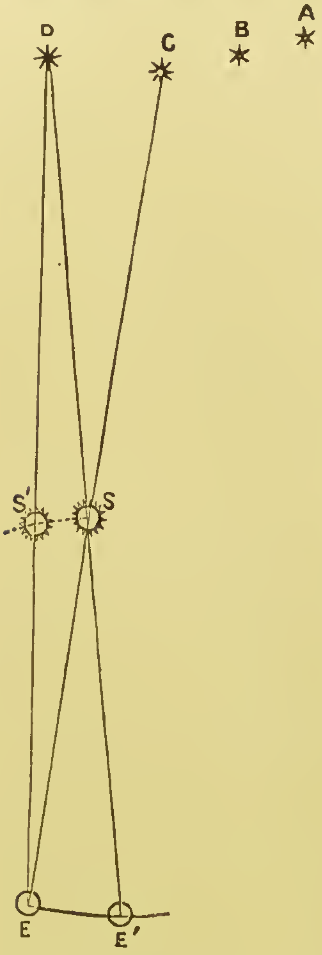

Fig. 170.

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[1] Westward—*i.e.* from left to right, when we consider the motion from

Thus when the earth is at E, the sun now supposed fixed at S appears in front of the star C ; when the earth has moved to E′, the sun at S appears in front of the star D ; and as the earth moves gradually westward from E to E′, the sun will appear to move eastward, passing from its position in front of the star C till it appears in front of the star D. Thus a real motion of the earth westwards gives an apparent motion to the sun eastwards. If the earth complete its journey round the sun in one year, the sun will appear to move round the heavens in a year also.

Therefore we see that the apparent yearly motion of the sun round the heavens can be explained either by supposing the earth moves round the sun or the sun round the earth. We have to decide which is the correct supposition.

From our experiences of the train, and conclusion with regard to the daily revolution of the earth, we know that if the earth and all it contains move smoothly, then our sensations will not tell us that we are in motion. Thus the earth may be moving round the sun, although we do not feel the motion. For this motion we shall, as before, give as evidence both *reasons and actual proofs*.

305. Reasons for believing the Earth revolves—

(i.) We find out that the sun is more than a million times as large as the earth, so it would seem more reasonable that the small earth should move round the large sun than that the sun should move round the earth.

(ii.) We have once before mentioned the planets. These are bodies which appear to the eye like stars, but which, on being closely watched for long periods, seem to wander amongst the rest of the stars in peculiar ways, sometimes advancing, at other times receding, and at other times remaining stationary. There are five such planets visible to the naked eye, and more visible to the telescope. Through the telescope, two of those five are particularly noticeable for presenting phases like the moon ; and these two, moreover, at rare intervals, have been seen to pass as black dots across the sun. All these peculiarities of motion and of phases can be easily explained by supposing that these planets revolve round the sun at different distances and in different periods, and that the earth is only another planet, also revolving round the sun at its own distance and in its own period. No other theory will sufficiently explain all these appearances of the planets, therefore it seems likely that this revolution of the earth round the sun is the true theory.

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the earth, and looking towards the sun ; but looking from the sun at the earth it would appear to move from right to left—*i.e.* eastward, round the sun. In the text we continue to speak of it as a westward motion.

306. **Proofs of the Revolution of the Earth.**—We cannot, as we did before for the daily rotation, find direct proofs on the earth itself for the yearly revolution round the sun; we must look to outside bodies. In one of the following proofs the question of the velocity of light occurs; hence we premise the statement that the velocity can be measured by instrumental means on the earth itself, and is found to be about 186,000 miles per second.

Proof I. Aberration of light.—Let us suppose that we want a drop of water to fall down a tube without wetting its side. If the tube is at rest, we hold it vertically in the direction X S. If the tube is moving, it must be held slanting, so that the drop falls in at the top when the tube is at A B, and falls down to A while the tube has moved forwards to X Y. The faster the tube moves the more must we slant it in order that the drop may fall down. So it is with the light from a star. If we were motionless we must point our telescope directly at the star, but if we were moving we must slant our telescope so that the ray of light may proceed down it. We find that this slanting of the telescope varies throughout the year, and that the star appears to revolve in a circular motion round what we know is its true position. This apparent revolution of the star must be caused by a revolution of the earth.

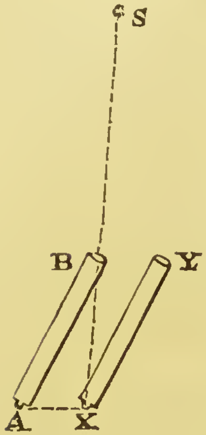

Fig. 171.

Let us consider this further, for we repeat that this displacement or aberration (Lat. *erro*, I wander) of a star can only be due to the combination of the orbital motion of the earth with the motion of light. It is perhaps the most convincing proof that the earth revolves round the sun, and not the sun round the earth. Thus when the earth is at the point A in its orbit (fig. 172), and moving perpendicularly to a star situated at S^1, this star is displaced in the direction of the earth's motion, and is seen at S^2. The amount of this displacement is a small angle of 20·5″, and is dependent on the proportion between the earth's orbital velocity and the velocity of light. As the earth proceeds in its orbit the star keeps, as it were, before it, describing, in fact, a small elliptical orbit round its true position. The longer axis of this aberration ellipse is always 41″, or twice the angle of displacement, 20·5″; but the shorter axis of the aberration ellipse depends on the position of the star with reference to the plane of the earth's orbit, the ellipse becoming more and more flattened as the star approaches this plane. If the star is in the plane of the earth's orbit, so that its celestial latitude is zero, the aberrational displacement is a mere line. The value of the small

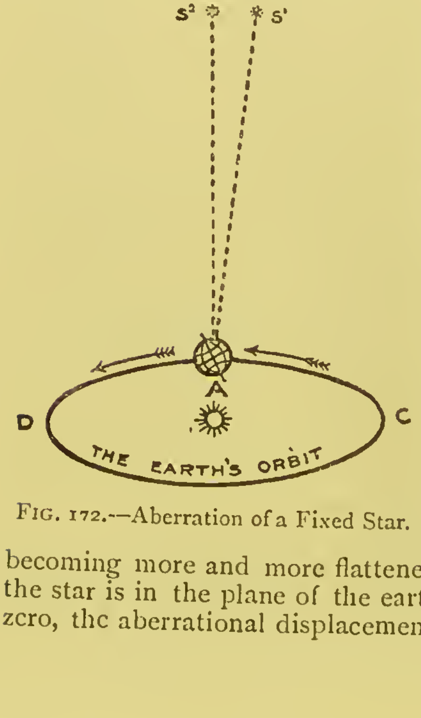

Fig. 172.—Aberration of a Fixed Star.

angle of displacement, called the 'constant of aberration,' enables us, from the known velocity of light (186,000 miles per second), to calculate the velocity of the earth in its orbit, and from that to find the distance of the sun. The average velocity of the earth in its orbit is found to be 18·5 miles per second, and the mean distance of the sun is then found to be about 93,000,000 miles.

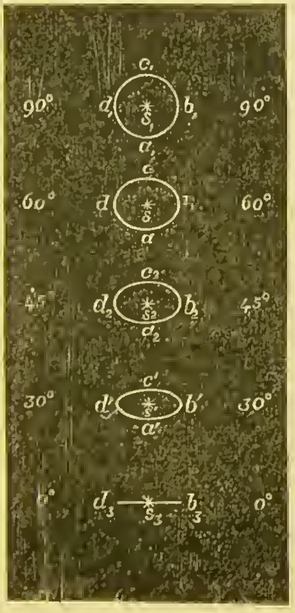

FIG. 173.—Aberration Ellipses of Stars in different Celestial Latitudes.

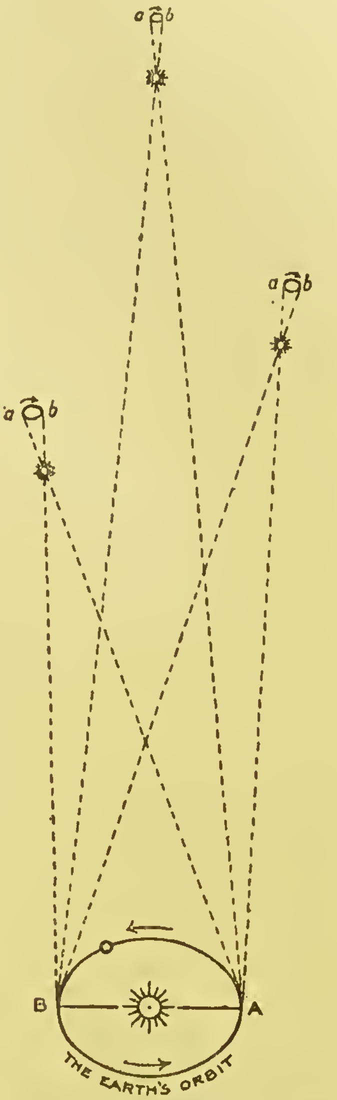

FIG. 174.—Parallax of Fixed Stars. Half the angle shown is the Annual Parallax.

Proof II.—If we look at a distant object from a fixed position, it appears thrown or projected upon the sky or other background at a certain point. On changing our position and looking at the same object, it appears to meet the sky at a different point. This apparent displacement of an object observed due to a real change in the position of the observer is called the *parallax* of the object, and the angle whose vertex is at the centre of the object observed, and whose sides pass to the two points of observation, is called the *angle of parallax*. Now, if we were to look at any of the fixed stars from a certain point on the earth, and then could instantly pass to the other end of that diameter of the earth, nearly 8000 miles away, we could not detect any parallax for a star, so vastly distant are they. Even when viewed from opposite sides of the earth's orbit, 186,000,000 miles apart, most of the fixed stars are so distant that they do not suffer any apparent displacement. A few, however, do show a slight parallax, and this is another proof of the earth's revolution round the sun. Fig. 174 illustrates the parallax of certain fixed stars, though the size of the earth's orbit in relation to the distance of the stars is greatly exaggerated. The angle formed by two lines passing to a star, one from the centre of the earth's orbit, and the other from a point on the orbit, is called the *annual parallax* of the star, *i.e.* it is the angle subtended at the star by the radius of the earth's orbit. The annual parallax of certain fixed stars is a proof of the earth's revolution round the sun. (Those stars that have an annual parallax appear to describe a small ellipse each year, but this ellipse must not be confounded with the aberration ellipse, for its cause is quite different; its size varies with the amount of annual parallax, and the motion is in an opposite direction to that of the earth.)

Proof III.—The law of gravitation, as first discovered by Newton, tells us that every particle of matter attracts every other particle with a force which varies directly as the product of the masses of the two particles, and inversely as the square of the distance between them. Applying this law to the sun and the earth, Newton proved that the earth would rotate round the sun; the distance from the sun would be that which has actually been found; the velocity of the motion would be that we found in Proof I.; and the time for one revolution would be one year. This, then, must be considered another proof, that theory should so perfectly agree with observations.

Although, therefore, the annual motion belongs to the earth, and not to the sun, it is sometimes simpler and more convenient to speak as if the motion belonged to the sun, for the solution of problems regarding the apparent position of the heavenly bodies is correctly obtained on either view.

307. **The Earth's Orbit.**—The earth's orbit, as we have said, is its path round the sun. This path is in one plane, and is very nearly, but not exactly, a circle. It is strictly an *ellipse*. An ellipse can be thus described. Two pins *s* and *s′* are stuck in a piece of paper, and a loop of cotton put over them. This loop is tightened by a pencil at P, and, keeping the loop tight, the pencil on moving round the pins will describe the ellipse P P′ *a b* A B. *s* and *s′* are called the *foci* of the ellipse. In the case of the earth's orbit the foci are comparatively close together, and hence this ellipse looks almost like a circle. The sun occupies one of these foci, and thus the earth is not always at the same distance from the sun. At the shortest distance the earth is said to be in *perihelion* (near the sun); at the furthest distance it is in *aphelion* (away from the sun). These positions of the earth occur respectively on January 1 and July 1 (see fig. 200).

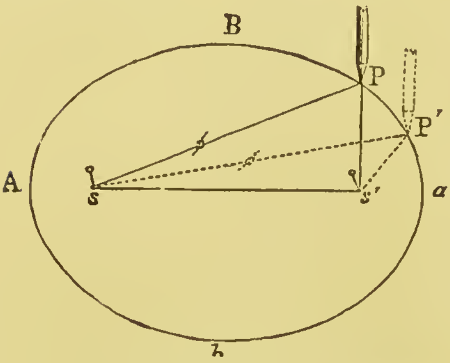

FIG. 175.—Showing how an Oval or Ellipse can be marked out.

We may remark that, though the earth's orbit is elliptical, yet it approaches so near a circle that if we were to represent it to exact scale in this book, the figure would be indistinguishable from a circle

The *eccentricity* of an ellipse is the displacement of a focus from the centre, and is expressed by a fraction with this distance for the numerator and half the major axis for the denominator. The smaller this fraction, the nearer is the ellipse to a circle. The eccentricity of the earth's orbit is only about $\frac{1}{60}$.

The earth is one of eight planets revolving round the sun in elliptical orbits. The laws of planetary motions as stated by Kepler are :—

Kepler's First Law.—The earth and the other planets revolve round the sun in elliptical orbits, having the sun in one of the foci.

Kepler's Second Law.—The radius vector of a planet sweeps over equal areas in equal times.

Kepler's Third Law.—The squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun.

We have just explained the nature of an ellipse, and we will now illustrate the meaning of the second law, which will enable us to understand the nature of the earth's motion in its orbit. (The third law does not concern us at present.)

Let fig. 176 represent the earth's elliptical orbit, with S for the sun in one focus. A B is the major axis of the ellipse, and a line at right angles through the centre would be the minor axis. Let the earth start from A, the nearest position to the sun (*perihelion*), and move to C. The radius vector, or line joining the centre of the sun and planet, sweeps over the area A S C. Now suppose the earth has moved to B, the point farthest from the sun (*aphelion*), and let it move onward from B to D in the same time that the earth took to move from A to C. Then the law of equal areas state that the area B S D is equal to the area A S C. Now, the distance A C is plainly greater than the distance B D, and as these distances are passed over in equal times, the velocity of the earth must be greater the nearer it is to the sun. In fact, the velocity is greatest at perihelion, decreases continually till the earth arrives at aphelion, and then increases until perihelion is again reached.

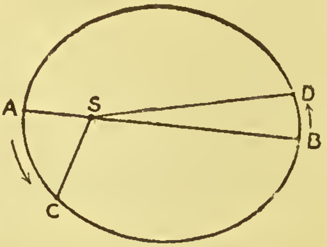

FIG. 176.—Illustrating Kepler's Second Law.

We have thus learnt three things about the earth's orbit :—

(1) It is in one plane.
(2) It is an ellipse of small eccentricity, with the sun at one focus.
(3) The earth's velocity in its orbit is not constant, but varies.

308. **Observations relating to the Earth's Orbit.**—How can we learn—

(*a*) that the earth's orbit is in one plane?
(*b*) that the orbit is not circular, but elliptical?
(*c*) that the speed of the earth in its orbit varies?

(*a*) We know that the earth's orbit is in one plane because the apparent annual path of the sun through the stars (due to the earth's revolution round the sun) is in one plane, the sun having been observed to move along the same great circle of the heavens, the ecliptic, year after year. In fact, careful observations have shown that the centre of the sun always appears to move along the ecliptic, and therefore the earth's orbit must lie in the plane of the ecliptic.

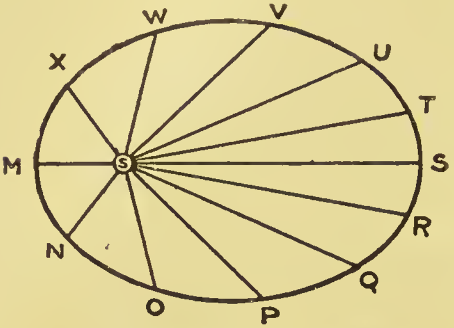

FIG. 177.—Illustrating how the Shape of the Earth's Orbit is found.

(*b*) We know that the earth is not always at the same distance from the sun, as it would be were the orbit circular with the sun in the centre, because the sun looks bigger at one time of the year than at another. In fact, the sun's apparent diameter varies regularly during the year, and as there is no reason to believe that the sun himself varies thus regularly in size, we must change our distance from it in a manner indicated by this apparent change of size. The sun's apparent diameter is the angle which its diameter subtends at the eye of an observer on the earth, and we know that the apparent diameter of an object is inversely proportional to the distance of the object. The sun's apparent diameter is greatest on January 1, and least on July 1, and we may thus learn that the earth is nearest the sun on January 1, and most distant on July 1. We may learn more from the actual measurements on these dates. The apparent diameter of the sun when greatest is 32′ 36″, and when least 31′ 32″, and hence the ratio of the distances is inversely proportional to the fraction $\frac{32'\ 36''}{31'\ 32''} = \frac{1956}{1892} = \frac{31}{30}$ nearly; that is, the sun is about $\frac{1}{30}$ of its mean distance *nearer* on January 1 than on July 1 (see fig. 178).

Careful measurements of the sun's diameter have been made from day to day, and from these measurements it is possible to construct the earth's orbit and to show that it is an ellipse, with the sun in one of the foci. To do this we draw from a point lines S M, S N, S O, S P, etc., making the lengths of the lines inversely proportional to the apparent diameter of the sun at the times of observation, and the direction of the lines correspond to the sun's angular position at the time of observation. On joining the ends of the lines, the figure of an ellipse is traced out (see fig. 177, where, however, as in other figures of the orbit, the ovalness is much exaggerated).

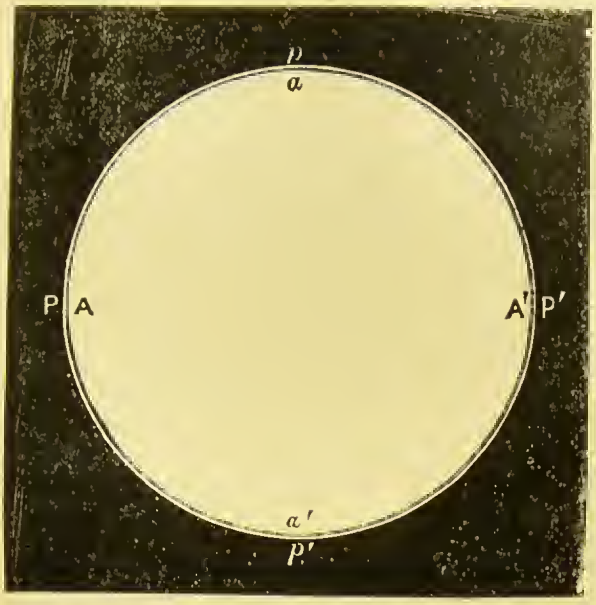

Fig. 178.—Sun's Annual Apparent Change of Diameter. P*p* P′*p*′, sun's disc at perihelion; A *a* A′*a*′, sun's disc at aphelion.

(*c*) Careful observations of the apparent motions of the sun along the ecliptic through the fixed stars show that the angular distance moved through varies slightly from day to day, and we deduce from this that the earth's velocity in its orbit varies. In the course of a year of a little more than 365 days the sun returns to the same point from which it started, so that it must have passed through 360° in the time stated. Its average daily motion is thus a little less than one degree. Now, it is found that the sun moves through an arc of 1° 1′ 10″ in twenty-four hours when it is nearest to the earth on January 1, and that on July 1, when farthest from the earth, it only moves through an arc of 57′ 11·5″. Thus actual measurement shows that the rate of the earth's motion in its orbit changes, being greatest when near the sun, and least when most distant.

A further proof of this variation of velocity is found by showing that it is a necessary consequence of the law of gravitation that the speed of the earth in its orbit must be such that the radius vector or line joining the earth and the sun must describe equal areas in equal times.

309. **Different Kinds of Day.**—We know that the sun, in consequence of the earth's revolution round it, seems to move eastward among the stars. A star reaches its greatest altitude, or transits the meridian, at exactly the

same interval each day. A *sidereal day* is the interval between two successive meridian passages of the same star. It is the actual time taken by the earth to make a complete rotation (360°) upon its axis. A *solar day* is the interval between two successive passages of the centre of the sun across a meridian, and it is *noon* at the moment of transit. If the sun, like a star, appeared always at the same place in the sky, a solar day would be of the same length as a sidereal day. But the sun seems to move eastward among the stars at the rate of about 1° per day, so that the earth must rotate nearly 361° about its axis before a given meridian comes opposite to the sun again, and so the solar day is nearly four minutes longer than the sidereal day.

By the help of fig. 179 we can illustrate why the solar day is longer than the sidereal day. M represents the centre of the sun, while the stars are at so great a distance that the rays from them are sensibly parallel. E_1 and E_2 represent two positions of the earth in its orbit at the interval of a sidereal day, or after one complete axial rotation. P A is the meridian of a place A on the earth. At E_1 the sun and a distant fixed star are on the meridian of A at the same time. At E_2 when the earth has made one complete rotation on its axis the distant fixed star is on the meridian of A again, but the earth must continue to turn through the small angle represented by the arc A B before the sun is again on the meridian P A. Hence the solar day or time from noon to noon is longer than the sidereal day.

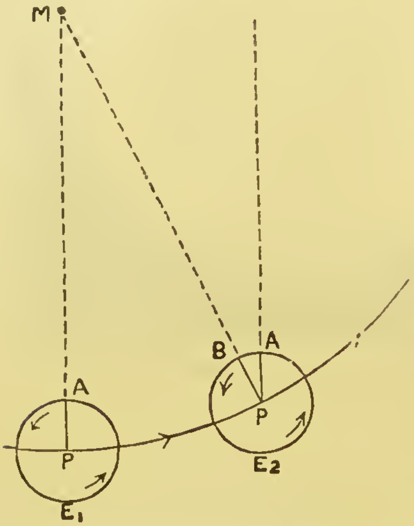

FIG. 179.—Diagram showing how the difference between the Sidereal and Solar Day arises.

As the sidereal day is shorter than the solar day by about four minutes, we find that there are 366¼ sidereal days during the 365¼ solar days of a year, *i.e.* there is one more rotation of the earth than there are days in the year.

The sidereal day, measured by the rotation of the earth on its axis, is of invariable length. But the solar day, measured by the interval between two successive appearances of the sun upon the meridian of any place, varies in length, because the varying speed of the earth in its orbit causes the distance of its forward movements in the orbit to vary, and thus the earth does not turn on its axis through the same angle every day to bring the sun on a meridian. Hence the *apparent* or *true solar day*, as the solar day that appears as the actual result of two successive meridian passages of the sun is called, varies in length at different parts of the year. It is longest when the sun moves fastest, and shortest when the sun moves slowest in its orbit. Another cause, the apparent movement of the sun in a path inclined to the meridians at varying angles, leads to an inequality in the length of the apparent solar days.

Solar time thus seems to be unsatisfactory, owing to its want of uniformity, and yet our ordinary life is regulated by the sun. To get over the difficulty, and obtain a uniform measure of time, we take the average of all the apparent solar days of the year, and call this a *mean solar day*. We imagine a sun called the *mean sun* moving uniformly along the celestial equator and completing its yearly circuit of the heavens in the same time as the actual sun. A *mean solar day* is therefore the average of the apparent solar days, and is always of the same length. This is the day which our clocks and watches keep, and it is divided into twenty-four hours, and these into minutes and seconds, so that our ordinary timepieces keep *mean solar time.* Greenwich mean time is used in all parts of England, and this is the time as shown by a clock moving through twenty-four solar hours in the *average* interval between two successive passages of the sun across the meridian of Greenwich, the moment of passage being *Greenwich mean noon.*

Such a clock does not always indicate noon when the real sun crosses the meridian, being generally a little before the sun or after it. True or apparent noon is found by ascertaining the exact moment of the meridian passage of the sun by a transit telescope. True time is also indicated by a sundial. The difference between true or sundial time, and the time shown by a clock keeping mean solar time is called the *equation of time.* It is used to regulate the clock, for sundial time, plus or minus the equation of time, gives the clock time (see par. 328).

The *civil day* is the mean solar day and the day of ordinary life. It begins and ends at midnight. The *astronomical day* begins at mean noon twelve hours later, and is reckoned round through 24 hours. Thus 4 A.M. of Friday, May 19, civil time, is Thursday, May 18, 16 hours, by astronomical time.

The word 'day' is often used for *daylight*, or the time during which the sun is above the horizon of a place (par. 315).

310. **Definition of Terms.**—The *ecliptic* is the great circle which the sun appears to describe round the heavens once a year. It is so called because all the eclipses of the sun and moon occur in it.

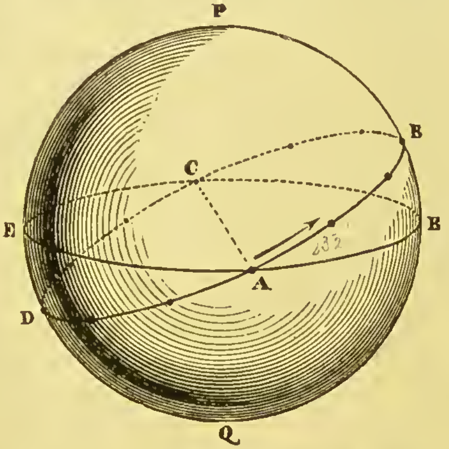

Fig. 180.—Diagram of the Celestial Sphere, showing the celestial equator E E intersected by the ecliptic D B at the nodes A and C. A is the vernal equinox, C the autumnal equinox, B the summer solstice, and D the winter solstice. The arrow shows the direction of the sun's apparent annual motion on the ecliptic. The angle B A E is the obliquity of the ecliptic.

The *plane of the ecliptic* is the plane passing through this circle, or, what is the same thing, it is the plane in which the orbit of the earth lies—for this orbit, we remember, is in one plane.

The *plane of the equator* is the plane passing through the earth's equator, this plane being supposed to be continued outwards to the sphere of the heavens, which it will cut in the celestial equator. The axis of the earth will, of course, be at right angles to this plane. These two planes do not coincide with one another, but intersect at two nodes or crossing-points, 180° apart, the angle of intersection being 23½° (see fig. 180).

The *equinoctial points*, or *equinoxes*, are the two points where the ecliptic cuts the celestial equator. The sun is at these points on March 21 and September 23.

The *obliquity of the ecliptic* is the angle which the plane of the ecliptic makes with the plane of the equator at the equinoctial points. Its value is about 23½°.

The *solstices* are the two points of the ecliptic midway between the equinoctial points. When the sun in its motion on the ecliptic reaches the solstitial points, it has its greatest declination, or greatest distance from the equator. On June 21 it is at the summer solstice, and has its greatest northern declination; on December 22 it is at the winter solstice, and has its greatest southern declination (see fig. 180).

The *tropics* are two great circles drawn through the solstices parallel to the equator. They are so called (Gk. *tropo*, I turn) because the sun then turns from its northward motion to the south, or *vice versâ*. The northern tropic is the Tropic of Cancer, and the southern tropic is the Tropic of Capricorn.

The *zodiac* is a belt of the heavens 16° wide, 8° on each side of the ecliptic. It is so called (Gk. *zoon*, an animal) because the groups of stars or constellations in it are figures of animals. The zodiac is divided into twelve equal arcs or parts, called *signs*, each 30° in length. The names of the signs are contained in the following lines:—

"The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin, and the Scales,
The Scorpion, Archer, and He-goat,
The Man that bears the watering-pot,
And Fish with shining tails."

Their Latin names, with the symbols used for them, and the days on which the sun enters the different signs, are as follows:—

NORTHERN SIGNS OF ZODIAC.

Spring Signs.

♈ *Aries*, the Ram, March 21.
♉ *Taurus*, the Bull, April 19.
♊ *Gemini*, the Twins, May 20.

Summer Signs.

♋ *Cancer*, the Crab, June 21.
♌ *Leo*, the Lion, July 22.
♍ *Virgo*, the Virgin, August 22.

SOUTHERN SIGNS OF ZODIAC

Autumnal Signs.

♎ *Libra*, the Balance, September 23.
♏ *Scorpio*, the Scorpion, October 23.
♐ *Sagittarius*, the Archer, November 22.

Winter Signs.

♑ *Capricornus*, the Goat, December 21.
♒ *Aquarius*, the Waterman, January 20.
♓ *Pisces*, the Fishes, February 19.

311. **Yearly Changes in the Appearances of the Stars.**—If we look out at the same hour of the night, but at different times of the year, we shall find that the same stars are not visible in the same positions. We shall see this more clearly if we fix on any one star, and watch for its appearance on successive nights. On each succeeding night it rises some four minutes sooner and sets four minutes sooner than it did the night before. Thus, if in spring at nine o'clock it is just rising, it will be high up in the heavens at the same hour in summer, and in autumn it will be setting at the same hour. During the winter months it will be below the horizon at this hour, and we should have to wait for some time for it to rise. As spring comes on again it will rise earlier and earlier, till on the same day of the month as we first began observing it, it will rise at nine o'clock. So it is with all the stars.

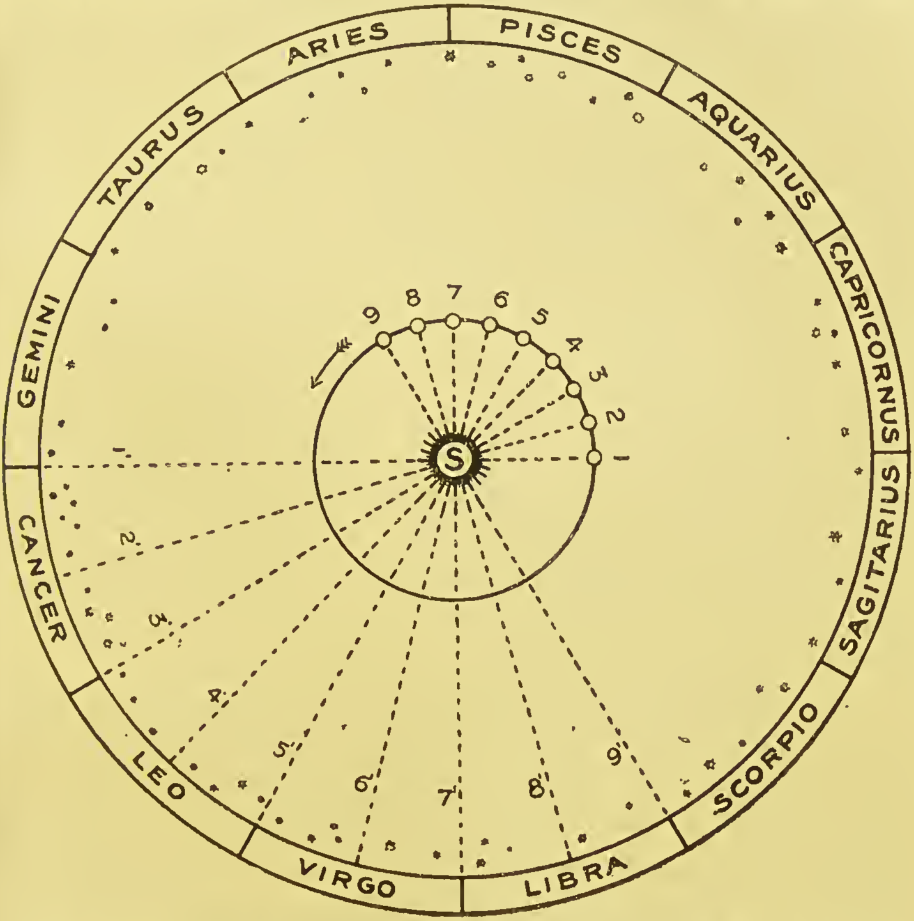

Fig. 181.—Illustrating the Sun's Apparent Yearly Path through the Signs of the Zodiac.

These changes are closely connected with that change of the sun previously mentioned, viz. that the sun appears to move eastward amongst the stars. Hence the stars must seem to pass westward behind the sun, and as our day and night depend on the light from the sun, the stars on each successive night will appear to be slightly to the westward of the position they occupied at the same hour on the previous night. Thus stars will rise earlier and set earlier on successive nights, the amount, viz. four minutes, being such that in a year's time they come back to the same positions at the same hours, for 365 times four minutes make up one day nearly. These yearly changes, of course, are due to the revolution of the earth round the sun, as we showed previously in considering that revolution.

The apparent yearly motion of the sun through the various signs of the zodiac, and the different stars visible from the earth at midnight, are illustrated in fig. 181. Let S represent the sun, and let the figures 1, 2, 3, 4, 5, 6, 7, 8, 9, indicate nine positions of the earth in its orbit, at intervals of about two weeks apart. Round the sphere of fixed stars are indicated the signs of the zodiac. When the earth is at 1, an observer will see the sun in the direction 1 S among the fixed stars at 1′. The sun appears to be entering the sign Cancer. At midnight on the part of the earth turned away from the sun, the stars in the opposite part of the celestial sphere are visible. When the earth has moved to position 2, the sun appears among the stars 2′, about the middle of the sign Cancer, and the stars in the opposite sign Capricornus appear at midnight on the part of the earth turned from the sun. On the earth reaching the position 3, the sun is about to enter the sign Leo. Passing through the successive positions 4, 5, 6, 7, 8, 9, the sun will appear among the stars 4′, 5′, 6′, 7′, 8′, 9′, and the motion of the earth continuing all the way round its orbit, the sun appears to pass through all the signs of the zodiac, and to complete the circuit of the heaven on again reaching the position 1.

(In ancient times, the constellations or groups of stars opposite each arc or sign of the zodiac was of the same name as the sign, but, owing to a backward movement of the sign Aries, this sign is now in the constellation Pisces, the sign Taurus in the constellation Aries, and so on. It is thus necessary to distinguish between the *signs* of the zodiac and the constellations of the zodiac.)

We have as yet only considered the effects of the rotation and revolution of the earth so far as they affect the appearances of the stars. But these two motions have important effects on the appearances of the sun, and these we will now proceed to consider.

312. **Changes in the Declination and Right Ascension of the Sun.**—If we find with a suitable telescope the declination and right ascension of the sun day by day, we shall learn that neither of these quantities remains constant. At the spring or vernal equinox on March 21, the sun is crossing the equator to the north, and its declination is zero. In about a month the sun has moved along the ecliptic, and its northern declination has been increasing. Drawing a quadrant from the pole perpendicular to the equator, we see that this declination is represented by the arc S M. At the end of another month, the declination will be again represented by the perpendicular from its position to the equator. At the end of the third month it has reached its greatest northern declination, 23½°, represented by the arc K Q, and is at

the summer solstice. Its polar distance is also now least. It now begins to approach the equator again (the distance between the two dotted portions of the ecliptic and the equator gets smaller), until at the autumnal equinox on September 23 the declination is again zero. After this date the sun passes south of the equator, and its southern declination increases until it reaches the winter solstice on December 22. The arc C E, 23½°, represents its greatest southern declination, and the sun's polar distance is now greatest. After the winter solstice the sun in its path again approaches the equator, and comes back again to the vernal equinox.

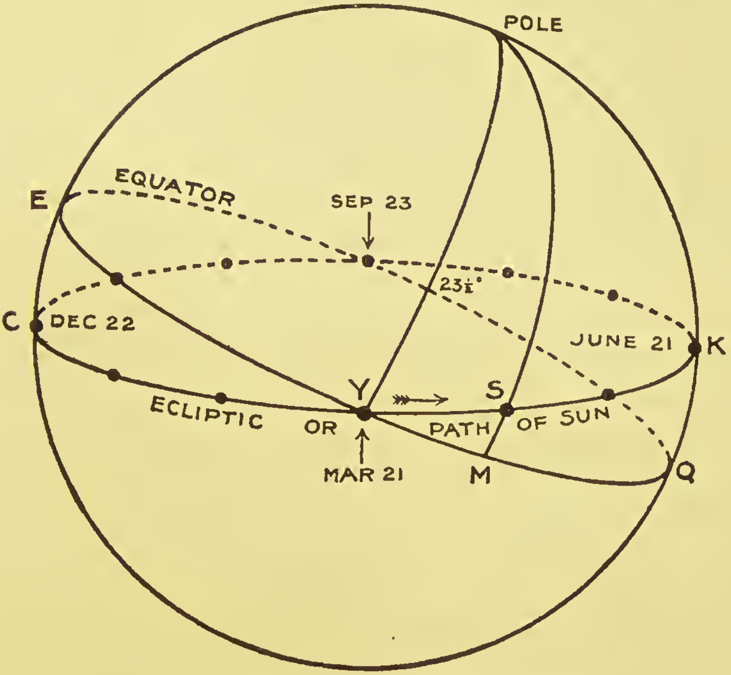

Fig. 182.—Diagram of Celestial Sphere, showing Sun's position on the Ecliptic at intervals of one month.

Consider now the changes in right ascension, which is the angular distance of a heavenly body *east* of the vernal equinox, or first point of Aries, *along the equator*. On March 21 the sun is at the first point of Aries, Y, and the right ascension is zero. Next day the sun will be found about 1° to the east, and each day the right ascension increases about 1°. At the end of a month the right ascension will be the arc Y M, about 30°, or the value of this arc in time. (Right ascension is usually expressed in almanacs in time, and not in degrees—1° = 4 minutes.) At the end of three months the right ascension is the arc ♈ Q, or 90°. On September 23 the R. A. of the sun is 180°; on December 22 it is 270°; and it goes on increasing, for it is measured all round, until the sun reaches the vernal equinox again.

As already pointed out, the sun does not move along the ecliptic at a uniform rate, and therefore the daily change in the right ascension of the sun is not uniform. It is the change of the sun's right ascension compared with the fixed R. A. of the stars that leads to the difference between the solar day and the sidereal day, and it is the varying amount of the sun's R. A. that causes the true solar days to be of unequal length.

Summarizing, we find that—

(*a*) On March 21 the sun crosses the equator through the first point of Aries, and it is the Vernal Equinox.

Sun's R. A. = 0, and its **Decl.** = 0.

(*b*) On June 21 the sun has described an arc of 90° along the ecliptic, and it is the date of the Summer Solstice.

Sun's R. A. = **90°** or 6 hours, and its **Decl.** = 23½° N.

(*c*) On September 23 the sun has described an arc of 180°, is at the first point of Libra, and it is the date of the Autumnal Equinox.

Sun's R. A. = **180°** or 12 hours, and its **Decl.** = 0.

(*d*) On December 22 the sun has described an arc of 270°, and it is at the Winter Solstice.

Sun's R. A. = **270°** or 18 hours, and its **Decl.** = 23½° S.

(*e*) Finally, on March 21 of the next year the sun has passed over the whole ecliptic, and it is again the Vernal Equinox.

Sun's R. A. = **360°** or 24 hours, and its **Decl.** = 0.

If we require the sun's R. A. at other dates we can obtain it exactly from the Nautical Almanac; or, knowing the sun's R. A. at the nearest equinox or solstice, we may obtain its R. A. approximately at other dates by adding 1° or 4 min.

for every day later. Thus January 1 is ten days later than December 22 when its R. A. is 270° or 18 hours. We must therefore add 10° or 40 m. to the R. A. of December 22. Hence on January 1 the sun's R. A. = 280°, or 18 hours 40 m.

Bearing in mind that celestial latitude and celestial longitude are measured with reference to the plane of the ecliptic and not the plane of the equator, we can see that the sun's latitude is always zero, as it is always on the ecliptic, and that the sun's longitude increases from zero at the first point of Aries up to 90° on June 21, to 180° on September 23, to 270° on December 22, and to 360° on March 21, when it is at the first point of Aries again.

313. **How to determine the Solstices, the Equinoxes, and the Obliquity of the Ecliptic.**—We will now explain a simple method of finding these dates and this angle. Fix a vertical rod or pillar, sometimes called a *gnomon*, on a horizontal surface and observe the noonday shadow cast by the sun. The day on which the shortest shadow is thrown at noon will be the date of the summer solstice; the day on which the longest shadow is thrown at noon will be the date of the winter solstice. The solstices may also be determined by finding the day on which the sun rises and sets furthest from

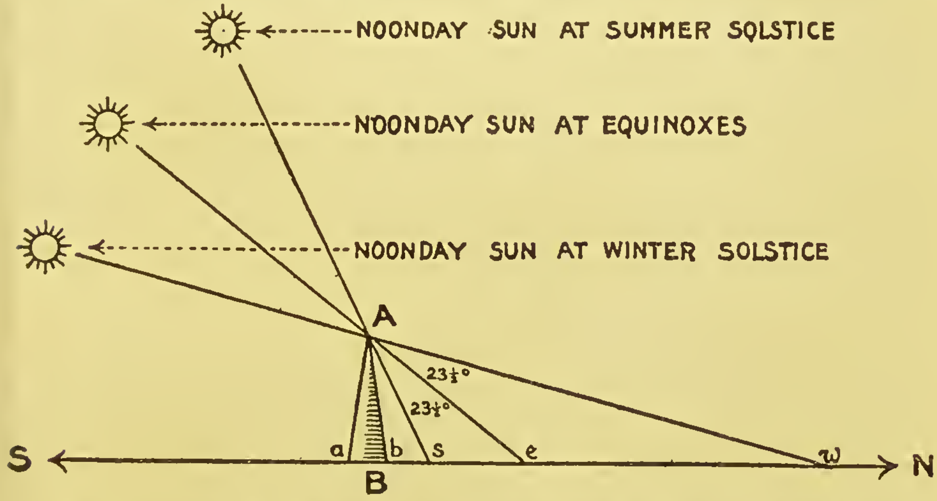
NOONDAY SUN AT SUMMER SOLSTICE
NOONDAY SUN AT EQUINOXES
NOONDAY SUN AT WINTER SOLSTICE
A
23½°
23½°
S
a
b
s
e
w
N
B

FIG. 183.—Illustrating how the Sun's varying Declination, the Obliquity of the Ecliptic, and the date of the Equinoxes and Solstices may be determined. *b s*, *b e*, and *b w* show the relative lengths of the noonday shadow of the gnomon at the times indicated.

the east and west points of the horizon. At the summer solstice it rises and sets furthest to the north; at the winter solstice it rises and sets nearest to the south.

We may find the equinoxes or dates on which the sun's daily motion is on the equator by determining the day on which the sun rises due east and sets due west, for the celestial equator cuts the horizon at these two points. A line at right angles to the meridian line runs due east and west, and at each equinox the shadow of a vertical rod cast by the rising sun will be in the same straight line as that cast by the setting sun.

From the observations with the gnomon we may learn that the sun's declination or distance from the equator is 23½° N. at the summer solstice, and 23½° S. at the winter solstice. This is therefore the angle between the plane of the ecliptic and the plane of the equator, and this angle of 23½° is the Obliquity of the Ecliptic. (See fig. 183, where the opposite angles are equal.)

The length of the year may be approximately found by finding with the gnomon the interval between one summer solstice and the next, or one winter solstice and the next; that is, by observing the times when the noonday shadow of the gnomon is longest or shortest.

314. **The Sun's Diurnal Path at Different Latitudes and Seasons.**—We have learnt that the sun's position among the stars is not fixed, but that in his progress along the ecliptic he not only changes his right ascension, or distance from the first point of Aries, but his declination or distance from the equator is changing from day to day, varying from 23½° N. to 23½° S., and back again in a year. This change of declination is the reason why the apparent daily path of the sun differs from day to day during the year. Indeed, the change is gradual throughout each day, but it will be sufficient for our purpose to assume that the sun keeps the declination that he has at sunrise throughout that day.

Let us now consider the daily motion of the sun on the celestial sphere in a somewhat similar manner to that in which we considered the daily motion of the stars in par. 303. There is this difference, however, to note between the sun and the stars. Each star describes its own daily path at various latitudes without any change throughout the year, the path depending on its distance from the equator. The sun's path changes during each year, so that at one time its path is like that of a star on the equator, at another period like that of a star above the equator (but never more than 23½° N.) and during another part of the year like that of a star south of the equator.

Take first the case of an observer at the equator, where the celestial poles are on the horizon, and where the equinoctial or celestial equator passes through the zenith. On March 21, when the sun is at the first point of Aries in his yearly circuit of the heavens, and when his declination is 0° (fig. 182), he will rise at the east point of the horizon E, and set at the west, W, describing the equatorial arc E Q W (fig. 184). From March 21 to June 21 the sun is daily increasing its distance north of the celestial equator, so that it rises north of E and sets north of W. On June 21 the summer solstice (fig. 182), the sun is 23½° north of the equinoctial, and its path on that day is represented by the arc *e* U *w*, half of which is above the horizon and half below. After June 21 the sun's northern declination decreases, and he is back again on the equator at the autumnal equinox, September 23 (fig. 182). After September 23 the sun passes south of the equator, his diurnal circle appears to get smaller, and he rises south of E and sets south of W. On December 22, the winter solstice (fig. 182), the sun's declination is 23½° S., and his daily path is represented by the circle A G, half of which, *e'* G *w'*, is above the horizon. After December 22 the south declination of the sun decreases as he moves along the ecliptic to the first point of Aries (fig. 182), a position he again reaches on March 21. Thus it is seen that at the equator the sun's daily path is always bisected by the horizon, and that day and night are always equal, though the amplitude of his rising and setting points varies from 0° to 23½° on each side. On March 21 the observer at the equator notes the sun passing through the zenith at noon; for six months it then transits the meridian north of the zenith; on September 23 it again passes through the zenith at noon; during the next six months it transits south of the zenith.

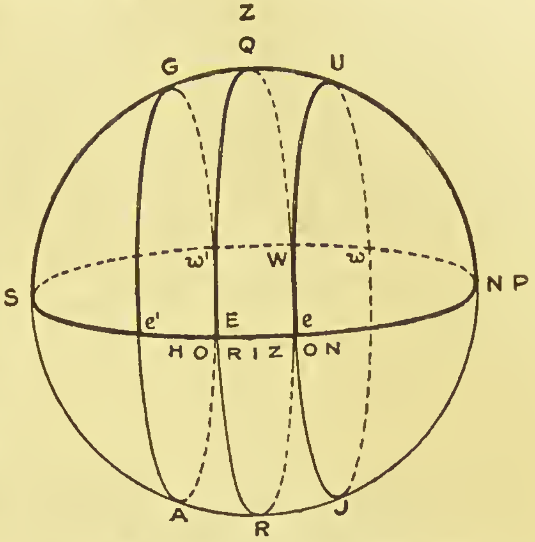

Fig. 184.—Figure illustrating the daily path of the Sun at the Equinoxes and Solstices, to an observer at the equator.

A little consideration will show that as we pass northwards from the equator, the daily path of the sun is not always half above and half below the horizon. From March 21, on which date the sun is on the equator, to June 21, the days increase and the nights decrease in length; from June 21 to September 23, the daily paths changes back to the equator, and the length of the day returns to twelve hours. From September 23 to December 22, the days shorten as the sun passes south of the equator, but from December 22 the days again lengthen. As long, however, as we remain in the torrid zone, it will be found that the sun passes through the zenith twice a year.

Consider now an observer just outside the torrid zone, say in latitude 27° N. As before, on March 21 the sun's daily path is on the equator, and he rises in the east and sets in the west, day and night being each twelve hours. But from March 21 to June 21, as the sun's declination increases, more and more of his daily journey is above the horizon, and the day lengthens, his amplitude and noonday altitude daily increase, until at the summer solstice his path above the horizon is represented by the arc *e*·U *w* in fig. 185. It is now the longest day, and the arc S U gives the greatest noonday altitude for an observer at this position. After June 21 the sun gradually returns to the equator, when day and night are again equal. From September 23 to December 22 the sun passes below the equator, the days get shorter than the nights, and the diurnal path above the horizon changes from E Q W to *e′* G *w′*. On December 22 the day is shortest, and the sun's meridian altitude S G is least. After this date the days again lengthen as the sun returns to the equator, and his daily path above the horizon again increases.

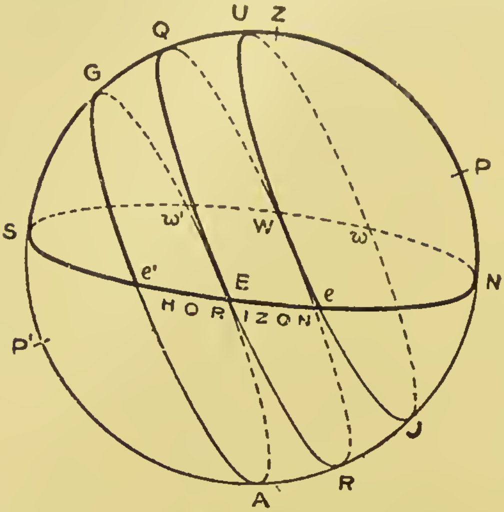

Fig. 185.—Diagram showing the daily path of the Sun at the Equinoxes and Solstices, to an observer about lat. 27° N.

As we pass into higher latitudes than that just described, the variations in the length of day and night are of a similar character to those just described, but more marked. Part of fig. 146 may be taken to represent the daily paths of the sun at London at the equinoxes and solstices, E M W being the path above the horizon when the sun is on the equator; *e m w*, the path above the horizon when the sun has its greatest northern declination at the summer solstice; and *f n v*, the path above the horizon at the winter solstice.

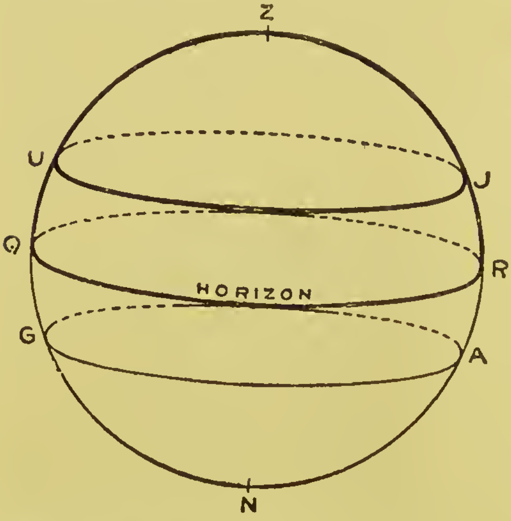

Fig. 186.—Diagram showing the daily path of the Sun at the Equinoxes and Solstices, to an observer at the pole.

As we get nearer the poles the sun's daily path becomes more and more parallel to the horizon, until at the pole itself, where the equator coincides with the horizon, the sun's daily path on March 21 is on the horizon. From March 21 to June 21 an observer at the pole would see the whole of the sun's diurnal circle as he passed from the south at noon to the north at midnight, and then back again to the south on the following noon. These daily journeys would be performed on circles parallel to the horizon, the daily parallels being more and more above the horizon until a distance of 23½° from the equator was reached, when the path is represented by J U in fig. 186. The sun would then turn back and gradually approach the equator again during the next three months of daylight. After September 23 the sun would sink below the equator and horizon, and there would be darkness for six months.

We thus see how the annual variations in the sun's declination cause the varying lengths of day and night, cause his diurnal path and meridian altitude to change, and thus produce in our latitude the change from the small arch of low altitude seen at midwinter to the large arch of high altitude seen at midsummer (astronomically, midwinter is the beginning of the season called winter, December 22; midsummer is the beginning of the season called summer, June 21). (See also par. 329.)

315. **Effect of the Earth's Annual Motion round the Sun.**—*Variations in length of Day and Night.*—We have in the preceding paragraph shown that the varying height of the midday sun causes the changes in its amplitude, and the varying length of day and night by speaking as if the sun moved round the earth in a year. We will now explain these phenomena by speaking of the earth's real annual motion round the sun at rest, and show that these phenomena are the result of the earth's revolution combined with the constant inclination of its axis at a certain angle. During the earth's annual revolution round the sun the earth's axis remains constantly parallel, 'for the mechanical reason that a spinning body maintains the direction of its axis invariable unless disturbed by extraneous force.' That this is so is also evident from the fact that in all parts of its orbit the earth's axis points in the same direction, that is, to the celestial pole, and only parallel lines seem to meet at a point in vast distance. (A small periodic change in the direction of the earth's axis due to the action of extraneous force will afterwards be explained, but no account of this need be taken here.)

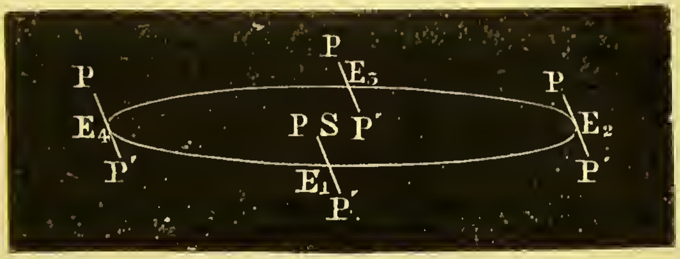

FIG. 187.—Showing how the Earth's axis keeps its direction unchanged while the Earth circles round the Sun.

We have learnt that the plane of the earth's equator is inclined to the plane of the ecliptic at an angle of about 23½°, and as the earth's axis is perpendicular to the equatorial plane, it must be inclined from the perpendicular to the ecliptic plane at an angle of 23½°. In other words, the earth's axis is inclined at an angle of 66½° (90° − 23½°) to the plane of the ecliptic itself. It follows, therefore, from the inclination of the earth's axis and its constant parallelism, that at certain parts of the earth's orbit round the sun one end of the axis is so disposed that it leans towards the sun, and in other parts of the orbit the same end leans away from the sun. At two positions of the orbit the axis is presented exactly sidewise to the sun, so that neither pole then inclines towards or from the sun. These facts are illustrated in fig. 188, which the pupil must learn to reproduce, keeping the axis in each position of the earth parallel.

At any position of the earth in its orbit, a line joining the centres of the sun and earth fixes the place on the earth's surface which has the sun directly overhead or in the zenith. At the positions (1) and (3) the boundary between light and darkness runs exactly along a meridian of the earth and from pole to pole, so that as the earth rotates on its axis in these positions, day and night are then equal in all parts of the globe. The earth is in position (1) at the vernal equinox, and in position (3) at the autumnal equinox. At intermediate positions the inclination of the earth's axis to the plane of the ecliptic causes all the parallels of latitude on the earth, except the equator, to be cut unequally by the boundary-line of light and darkness, and day and night are consequently unequal, the day being longer than the night in the Northern Hemisphere when it is shorter in the Southern Hemisphere, and *vice versâ*. Position (2) is the summer solstice, when the sun is vertical to places 23½° north of the equator, when the north end of the axis is most inclined to the sun, and when the day is longest in the Northern Hemisphere, and shortest in the Southern. Further, it is plain that at the summer solstice the nearer we approach the north pole, the larger will be the portion of the parallel of latitude remaining in the light, as the earth rotates, and the longer the days; while the nearer we approach the south pole, the less will be the portion of a parallel in the light, and the shorter the days. In fact, within the Arctic Circle at the summer solstice an observer is never carried out of light by the earth's rotation, and he sees the *midnight sun* due north. Within the Antarctic Circle an observer remains in darkness while the earth rotates. From position (2) there is a gradual change to position (3), after which the sun descends below the equator until in position (4), the winter solstice, it is vertical over places 23½° S. Here we have the exact opposite state of affairs, and we see why we have the short winter days and the long summer days in the British Isles and other places north of the equator.

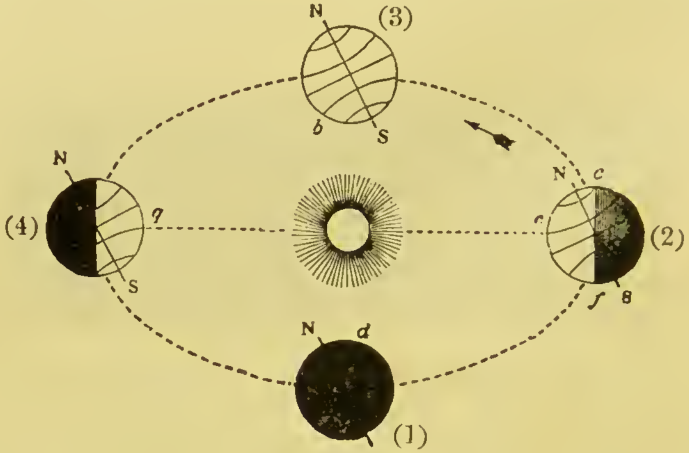

FIG. 188.—Earth's Orbit, with Earth at Equinoxes and Solstices.
The four seasons.

These considerations again help us to see how the series of changes each year in the sun's declination or distance from the equator are brought about by the annual revolution of the earth combined with the inclination of the earth's axis to the ecliptic plane, *i.e.* with the inclination of the plane of the equator to the plane of the ecliptic. And the annual changes of the sun's declination causes the variations of the sun's *amplitude* or distance of rising and setting from the east and west points throughout the year; for the further a body is north of the equator to an observer in the Northern Hemisphere, the greater is the portion of its daily circle of rotation above the horizon, and the further does it rise north of east and set north of west; while the further the body is south of the equator, the shorter is it above the horizon, and the further does it rise south of east and set south of west. At the equinoxes the sun's amplitude is 0° in all parts; at the solstices the sun has its maximum amplitude, but this varies in different parts of the earth, increasing with the latitude. The greatest amplitude at the solstices in latitude 50° (London is 51½° N.) is 38½°.

So important is the proper understanding of the variation in the length of day and night at all places north and south of the equator (at the equator day and night are always of 12 hours each, as this parallel is always equally divided by the line of light and darkness), that we will further consider the four chief positions of the earth in its orbit. The orbit, is of course, in the plane of the ecliptic. N S in each case represents the axis of the earth.

Let us first consider the position C, where N, the north pole, is towards the sun, and for this purpose we use a separate figure (189). In this figure, *e f* represents a plane perpendicular to the line joining the centres of the sun and earth. All that part of the earth on the side of *e f* nearer the sun is illuminated and has daylight; all on the further side has darkness and night. A plane perpendicular to the axis is the plane of the equator E Q. The circle *e d* described on the earth passing through *e*, the extremity of the shadow, is called the Arctic Circle. We see that a place within the Arctic Circle never loses sight of the sun, never entering the shaded half, during a rotation about the axis N S, so long as the earth and the sun are in the positions indicated by the figure. The corresponding circle *f q* in the Southern Hemisphere is such that all places within it never see the sun during a rotation, the conditions being the same. This circle is the *Antarctic Circle.* The circle *c v*, passing through the point *c* directly under the sun, is called the *Tropic of Cancer.* The corresponding circle *g p* in the Southern Hemisphere is the *Tropic of Capricorn.* (See note, par. 224.) We have considered the effect of rotation at places included in the Arctic and Antarctic Circles Between the Arctic Circle and the equator all places will evidently see the sun for more than half a rotation —*i.e.* have a longer day than night; for more than one-half of each parallel in the Northern Hemisphere is in the light. Between the Antarctic Circle and the equator the reverse will be the case, night being longer than day. The sun will during the course of the day pass over-

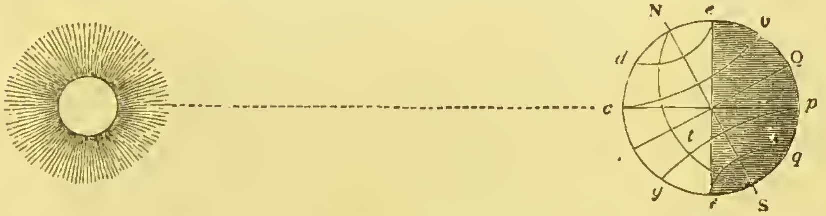

FIG. 189.—Northern Summer and Southern Winter.

head to all places on the circle *c v*. All this, we must remember, is while the earth is in the position when the north pole is most inclined towards the sun.

The next figure (190) shows the earth at the opposite side of the orbit, where the two hemispheres are just reversed in all respects so far as light from the sun is concerned. Thus within the Arctic Circle there is no sunlight during the rotation round the axis; within the Antarctic Circle the sun is not lost sight of during the rotation. Between the equator and the Arctic Circle night is longer than day, and between the equator and the Antarctic Circle day is longer than night.

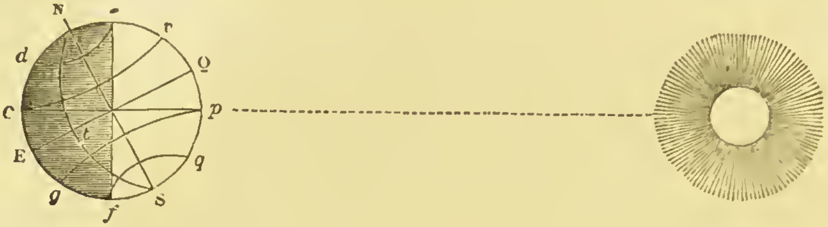

FIG. 190.—Northern Winter and Southern Summer.

At either of the intermediate positions the appearances are the same. In these two positions the earth's axis is perpendicular to the line joining the centre of the earth and sun, as we see by a figure (191); and here we see that day and night are of the same length at all parts of the earth. These positions are called the *equinoxes*, because day and night are of equal length. The first two positions discussed are called the *solstices*.[1] From solstice to equinox the appearances above described change gradually, and so from the equinox round to the other solstice. Thus in the Northern Hemisphere at the first solstice the sun at midday is high in the heavens, and on each succeeding midday gets lower and lower; at the same time the day shortens and the night lengthens till the equinox, when they are equal in length. After the equinox the sun is still lower at midday, and now the nights are longer than the days, and the difference increases till the other solstice is reached. Then the midday sun is at its lowest in the heavens, and on two successive days seems to occupy the same place—to stand still, as it were, and hence the name solstice. After this the changes are all gone through back again till the other solstice is reached, and then we say one year is completed.

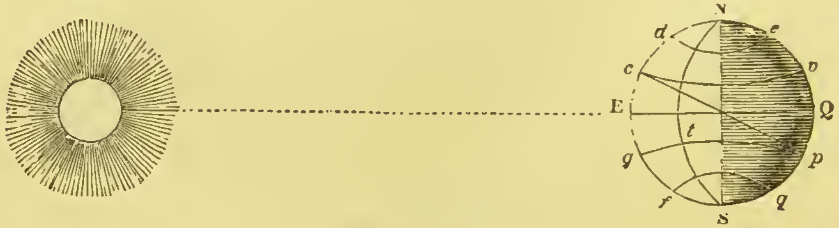

FIG. 191.—Vernal or Autumnal Equinox.

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[1] Solstices (Lat. *sol*, the sun, and *stare*, to stand), the times at which the sun reaches its greatest distance from the equator, because it then appears to stand still before the direction of its motion is changed towards the equator again.

We notice, further, that all places within the Arctic Circle have at least one day in which the sun never sets, and one in which it never rises. The poles themselves see the sun for six months and lose it for six months. Within the two tropics every place has the sun overhead, or in the zenith, at least twice a year. This occurs on two successive days at the tropics themselves, the sun rising day after day higher and higher, till it becomes vertical at midday, and then it seems to 'turn back'—hence the name tropic. Outside the two tropics, and below the Arctic and Antarctic Circles, we have two zones which have appearances lying between the two last described, for they never have a vertical sun, nor a day in which the sun fails to rise or set.

The following table shows the longest duration of sunlight—*i.e.* the longest day at different latitudes:—

Latitude.		Latitude.	
0° (Equator)	$12^h\ 0^m$	60°	$18^h\ 30^m$
10°	$12^h\ 35^m$	66° 33′ (Arctic Circle)	$24^h\ 0^m$
20°	$13^h\ 13^m$	70°	2 months
30°	$13^h\ 56^m$	80°	4½ months
40°	$14^h\ 51^m$	90° (Pole)	6 months
50°	$16^h\ 9^m$		

We add a diagram to illustrate these different lengths of the longest day at every 10° of latitude in the Northern Hemisphere when the north end of the earth's axis is most inclined to the sun. The length of the longest night in winter is the same as that of the longest day in summer.

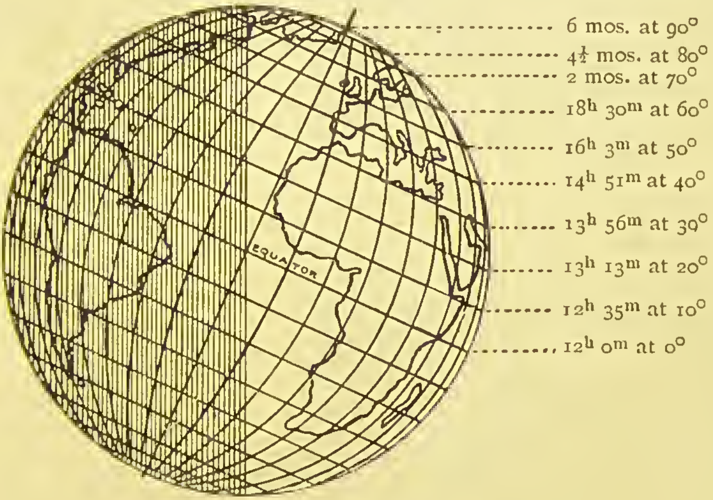

FIG. 192.

A simple way of illustrating the height of the midday sun at different parts of the year is shown in figs. 198, 199. A line drawn from the centre of the earth through the situation of any particular place passes to the zenith of that place, and a line from the centre of the earth to the sun will show thus the angle separating the sun from the zenith, *i.e.* the zenith distance. The zenith distance of the sun subtracted from 90° gives its altitude. The less the zenith distance, therefore, the greater is the altitude. In the figures, the letter L represents the latitude of London, and Z indicates its zenith.

316. **Distribution of Light and Heat on the Earth.**—That half of the earth's surface which is turned towards the sun receives light and heat from it; the other half is in darkness.

The light, and especially the heat, derived from the sun at any place, are greatest when the sun is highest in the heavens, and can therefore send its rays more nearly perpendicular to the ground. There are two reasons for this :—

(1) When the sun is higher the rays from it pass through less of the earth's atmosphere, and so less heat is absorbed by that atmosphere before they reach the ground.

(2) When the sun is higher the number of rays received by any particular piece of ground is greater than when the sun is lower, *i.e.* the quantity of heat received by a square yard of ground increases as the sun's altitude increases. This is the main reason for the increased heating power of more perpendicular rays.

By a figure in connection with par. 211 we have seen how both these reasons combine to cause an increase in the heating power of the sun's rays as we approach the equator. The reader should again consider the paragraph carefully (see also pars. 212 and 213). Fig. 194 is drawn for one of the equinoxes, and it is now easily seen how at the summer solstice, when the Northern Hemisphere is more inclined towards the sun than at an equinox, any area north of the equator will receive its supply of the sun's rays more perpendicularly than at an equinox. In winter the rays will fall

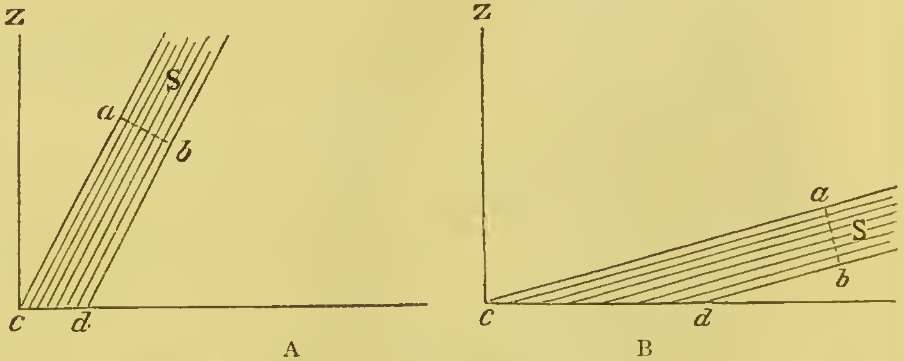

Fig. 193.—Showing the difference in the distribution of the sun's rays at London at midsummer (A) and at midwinter (B). The zenith distance of the sun at noon is about 28° at midsummer in the latitude of London, and about 75° at midwinter. Its altitude is therefore $90^\circ - 28^\circ = 62^\circ$ in the former case, and $90^\circ - 75^\circ = 15^\circ$ in the latter case.

more obliquely, and their strength will be weakened. Fig. 193 shows the different angles at which the sun's rays strike the earth on June 21 and December 22, and it also illustrates the unequal distribution of an equal band of rays *a b*, at these two angles.

But there is still another cause that effects the temperature of the various parts of the earth at different periods of the year, for it must be plain that the length of the day, or the time which the sun remains above the horizon, has great influence. While the sun is shining, those parts of the globe exposed to his rays are receiving heat; after the sun has set, these parts are losing heat, the heat passing away by radiation into space. Hence places are most heated when the days are longest. The more distant a place is from the equator the greater is the difference between the length of its days and nights, and the greater will be the variation of its temperature during the year. Although we receive most heat in twenty-four hours at the time of the summer solstice, this is not the hottest time of the year. The maximum temperature at any place usually occurs at the end of July, because during most of the summer the heat received from the sun during the

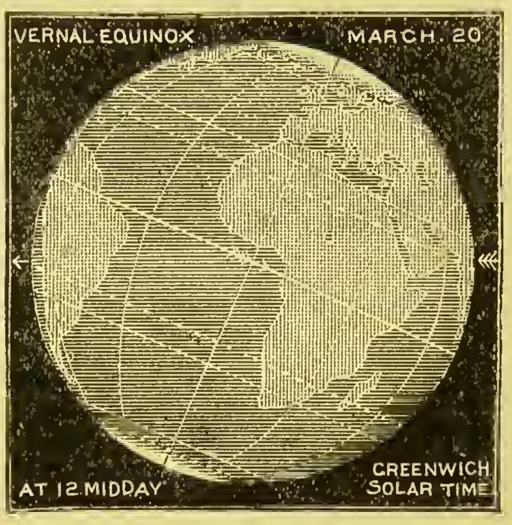

Fig. 194.

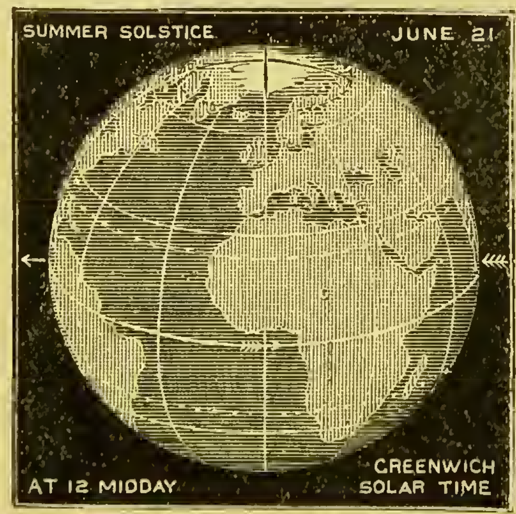

Fig. 195.

day is in excess of that lost by radiation during the night, and so the temperature goes on increasing until the loss by night is just equal to the gain by day. (So the greatest heat of any day is not until about two hours after noon, when the gain and loss each minute is balanced.) In autumn the loss by night begins to be greater than the gain by day. The minimum temperature of the year occurs when the gain by day again becomes equal to the loss by night, and this happens about the end of January.

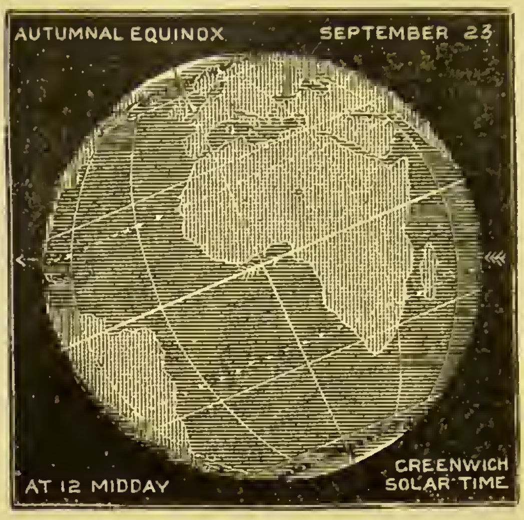

Fig. 196.

Some of the facts set forth in this and the preceding paragraph are well shown in a different way in figs. 194 to 197.

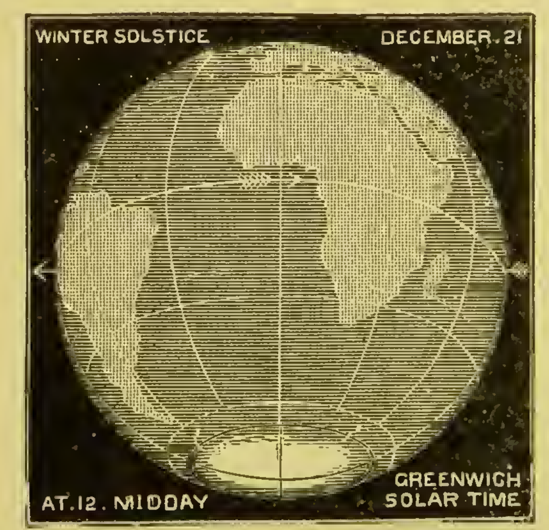

Fig. 197.

These figures show how the earth is presented to the sun at the four seasons, or four chief positions of its orbit. They are sun-views of the earth, such as an observer on the surface of the sun might obtain. At the vernal equinox sunlight reaches from pole to pole, and every place would be seen to pass straight across as the earth rotates from west to east, each place being twelve hours in sunlight and twelve hours in darkness. Day and night are thus equal. As the earth moves on in its orbit round the sun in the direction of the large arrow passing through the earth and with its axis unchanged in direction, a little consideration will show that the parts round the north pole will gradually come into greater view, while the parts round the south pole will pass out of view. When the earth has reached the position of the summer solstice at midsummer, we see that the aspect it presents to the observer on the sun is greatly changed. Places in the Northern Hemisphere remain in view more than twelve hours, for the rotating earth carries them round on a curved path, the curve being bent downwards as the equator and other circles of latitude are seen to be. England is seen to be well down towards the centre of the illuminated half of the earth, and the sun's rays are therefore received more vertically than at the vernal equinox, and it appears larger to the supposed spectator on the sun. Places within the Arctic Circle go round and round as the earth rotates without passing out of sunlight, while places near the south pole are

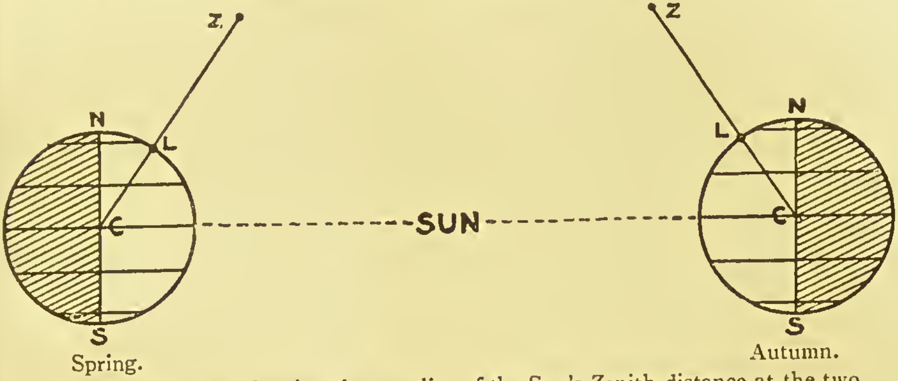

FIG. 198.—Diagram showing the equality of the Sun's Zenith-distance at the two Equinoxes. Angle Z C S (sun) = zenith distance.

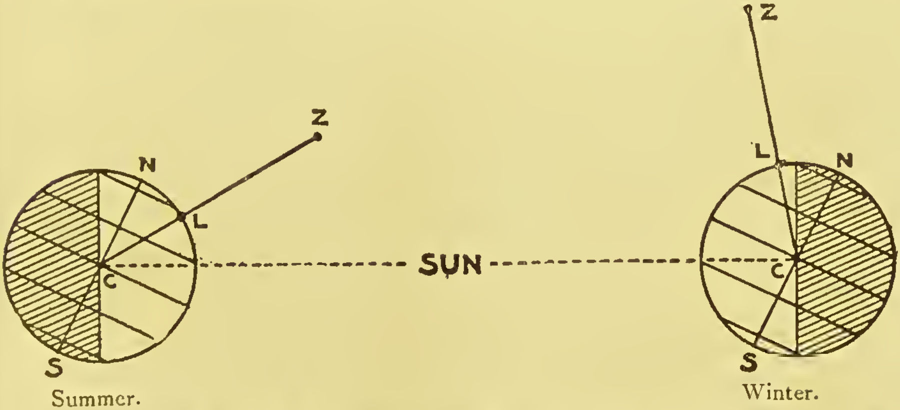

FIG. 199.—Diagram showing the difference between the Sun's Zenith-distance at the two Solstices at the latitude of London. Angle Z C S subtracted from 90° gives the altitude.

never brought into light, so that the sun never sets in arctic regions, and never rises in the antarctic regions. There is a 'midnight sun' in the north part of the sky beyond latitude 66½° N. At the autumnal equinox matters are the same as when the earth was at the vernal equinox. At the winter solstice the region round the north pole is turned away from the sun, and the region round the south pole enjoys continuous sunlight. Places north of the equator follow the paths indicated, and are less than twelve hours in sunlight, while places south of the equator are more than twelve hours in sunlight. England now receives the sun's rays so obliquely and lies so near the edge of the illuminated half of the earth, that it cannot be properly represented on so small a figure.

It will be noticed that the middle of the illuminated half of the earth is alternately north and south of the equator, and the sun at noon is therefore twice in the zenith at the equator —once at the vernal equinox and once at the autumnal equinox. Between the vernal equinox and the autumnal equinox he is twice in the zenith at noon to places as far north as the Tropic of Cancer. Between the autumnal equinox and the vernal equinox he is twice overhead at noon to places south of the equator as far as the Tropic of Capricorn. In other latitudes he is never seen in the zenith.

317. **The Seasons.**—Remembering how the effect of the sun's heat on any part of the earth's surface depends on its height in the heavens, and the length of time it shines, and remembering also the explanation of the different lengths of night and day, we shall easily explain the succession of the seasons.

Considering either hemisphere, say the northern, we take the position of the earth at that solstice when the north pole is most turned towards the sun. There are now long days and short nights, and the sun is higher in the heavens at midday, and thus for both reasons it is warm in this hemisphere; in fact, it is midsummer. Summer lasts until the earth reaches the equinox, nights and days being now equal, and autumn begins. Autumn lasts till the other solstice is reached. Then it is midwinter, being cold, for nights are at their longest, days

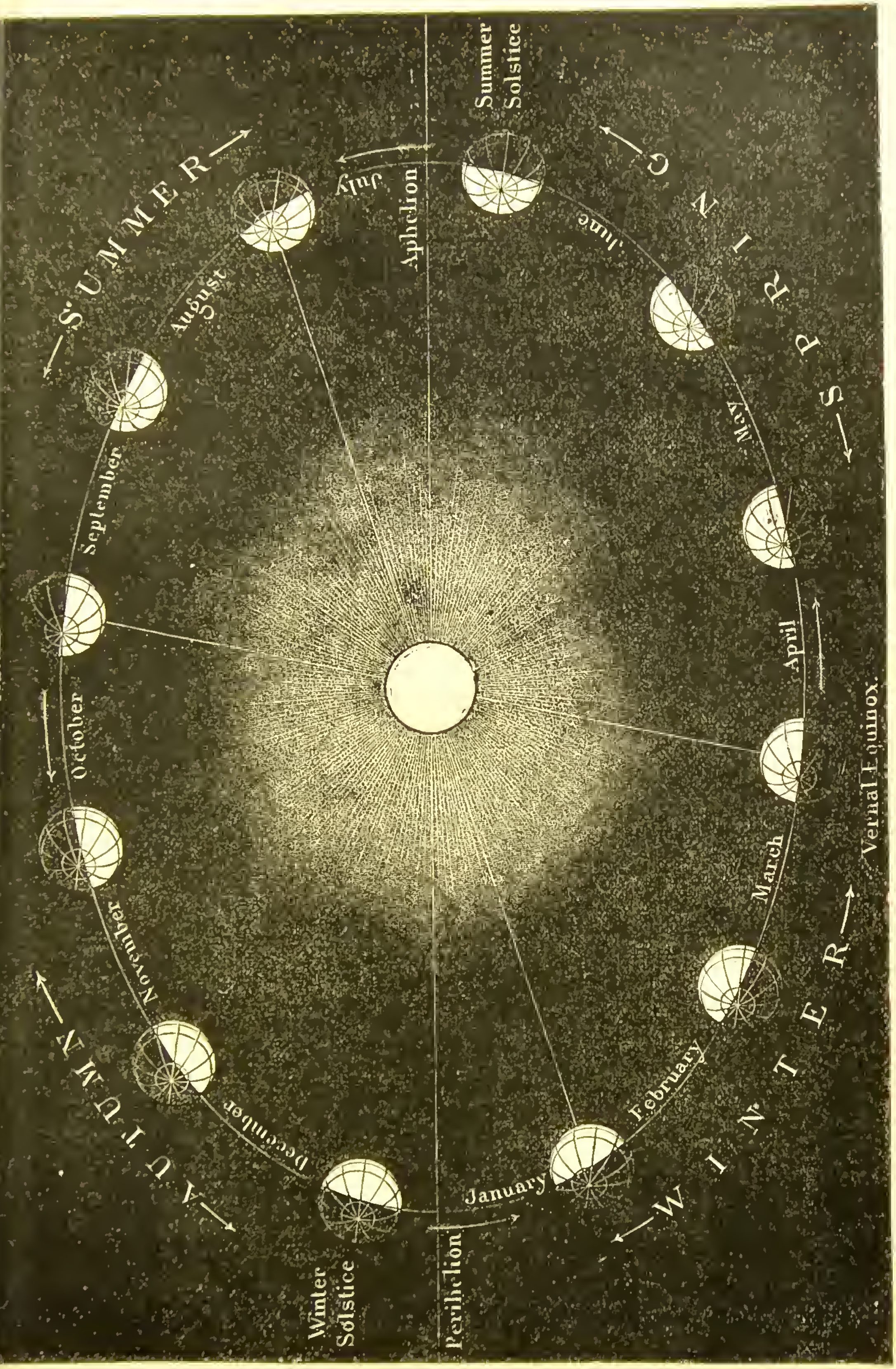
SUMMER
AUTUMN
WINTER
SPRING
Summer Solstice
Aphelion
July
August
September
October
November
December
Winter Solstice
Perihelion
January
February
March
Vernal Equinox
April
May
June

FIG. 200.

being shortest, and the midday sun is at its lowest. Winter lasts till the next equinox, and then it is spring. Spring lasts from this equinox to the summer solstice. As the Northern and Southern Hemispheres are reciprocal in the lengths of their days and nights, we see that the seasons will be reciprocal. Thus when it is summer in the Northern Hemisphere it is winter in the Southern. When spring in the Northern it is autumn in the Southern, and *vice versâ.*

We may notice that between the two tropics the midday sun is always very high in the heavens, and the nights are never much longer than twelve hours; thus it is always hot there—a perpetual summer—and this zone or belt of land is therefore called the *Torrid Zone.* At places included in the Arctic and Antarctic Circles the sun never rises high, and though this in summer is somewhat compensated for by the long days, still it is always cold there—a perpetual winter—and hence the zones are called respectively the *North* and *South Frigid Zones.* Between the North Frigid Zone and Torrid Zone we have the *North Temperate Zone,* and between the South Frigid Zone and Torrid Zone we have the *South Temperate Zone.* In these Temperate Zones the winters are neither very cold nor the summers very hot; hence their names. And it is in these zones that the seasonal changes are most marked.

Figure 200 shows different positions of the earth in its orbit as seen from above the ecliptic plane, thus illustrating the change of seasons throughout a year. The figure is drawn for the Northern Hemisphere, the figure for the Southern being similar, the seasons being reciprocal to the former. It will be instructive for the pupil to begin at the bottom of the figure, where the earth is seen in the position it occupies about March 21 (when both poles are equally distant from the sun), and to follow the earth through its monthly changes, noticing the boundary of the enlightened hemisphere in the successive periods as the earth revolves on its axis, and at the same time makes its yearly revolution round the sun.

It will be noticed that the winter solstice occurs very near the perihelion, and the summer solstice near the aphelion;

thus, in the winter of the Northern Hemisphere the earth is nearest the sun, and in summer furthest from the sun. For the Southern Hemisphere the earth then is nearest in summer and furthest away in winter. As it is warmer the nearer we are to the sun, the southern summer will be slightly hotter than the northern one, and the southern winter slightly colder than the northern one. This difference of distance is small, and the resulting difference in climate is small, and may, moreover, be masked by local causes, as the prevalence of hot or cold winds and ocean currents. The different months are marked in the figure, and we see winter lasts during January, February, March; spring during April, May, June; summer during July, August, September; and autumn during October, November, December. The exact durations of the seasons we get by knowing the dates of the equinoxes and solstices.

(We remember that perihelion occurs January 1, and aphelion on July 1.)

The Vernal or Spring Equinox is on March 21, and Spring begins.
The Summer Solstice is on June 22, and Summer begins.
The Autumnal Equinox is on September 23, and Autumn begins.
The Winter Solstice is on December 22, and Winter begins.

Finding the intervals between these dates, we shall learn that the seasons are of unequal length. Winter is about 4½ days shorter than summer in our hemisphere. We say 'about,' because to be quite accurate we should give the exact time on the above dates when each season begins, for spring begins at the moment the sun reaches the vernal equinox on March 21; summer, the moment the sun reaches the summer solstice on June 21, and so on. The four seasons are, in fact, the periods into which the year is divided by the equinoxes and solstices. Their lengths at present are to the fraction of an hour—

Winter.	Autumn.	Spring.	Summer.
89 d. 0½ h.	89 d. 18½ h.	92 d. 20¾ h.	93 d. 14½ h.

Spring and summer together, when the sun is north of the equator, are thus about seven days longer than autumn and winter. What is the cause of this inequality in the length of the seasons?

Fig. 201 is a representation of the earth's orbit with the ellipse exaggerated. The two equinoctial and the two solstitial points divide the orbit or ecliptic into four equal portions 90° apart, but, owing to the varying speed of the earth in its orbit (travelling more quickly the nearer it is to the sun, and the more slowly the more distant it is), these equal portions are not described in equal times. The line through the sun in one focus of the ellipse from the spring equinox, 0°, to the autumnal equinox, 180°, and the line at right angles joining the two solstices divide the area of the figure into four unequal quadrants, and the areas of the quadrants being unequal, Kepler's second law—that the radius vector or line joining the earth and sun sweeps over equal areas in equal times—shows that the times in which the sun describes them are unequal and proportional to the areas.

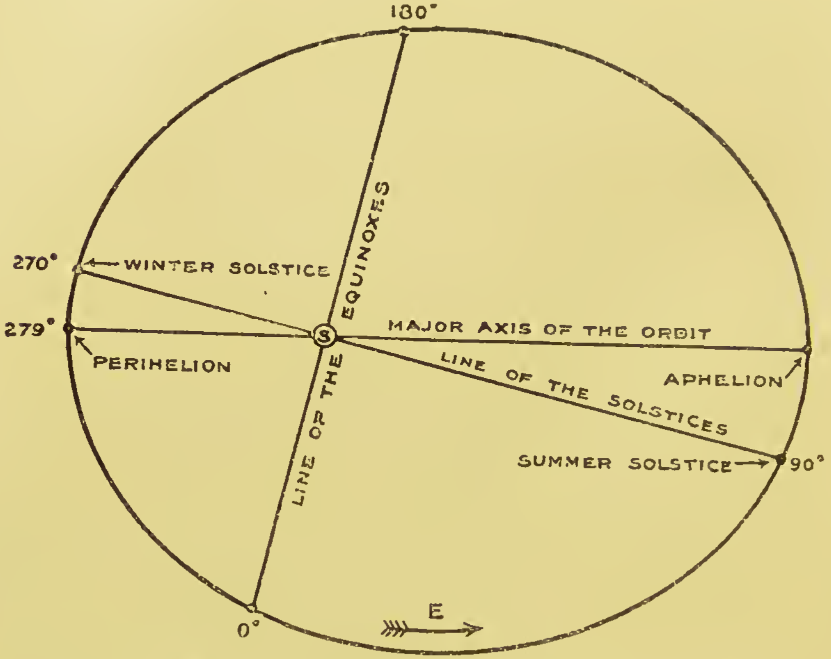

FIG. 201.—Illustrating the inequality in the length of the Seasons. From the Vernal Equinox, 0°, to the Summer Solstice, 90°, it is Spring; from the Summer Solstice, 90°, to the Autumnal Equinox, 180°, it is Summer; from the Autumnal Equinox to the Winter Solstice, it is Autumn; from the Winter Solstice, 270°, to the Vernal Equinox, it is Winter.

Summary of the Effects of the Rotation and Revolution of the Earth.

Rotation causes the risings and settings and daily apparent motions of the sun and stars, and thus causes day and night.

Revolution causes the sun to appear to move eastward amongst the stars through the twelve signs of the zodiac, and thus stars rise about four minutes earlier on successive nights. It also produces the yearly changes in the sun's Right Ascension.

Revolution combined with the inclination of the planes of the equator and ecliptic (*i.e.* the inclination of the earth's axis) causes the yearly variations in the sun's declination (*i.e.* the varying height of the midday sun), the difference in length of the days and nights, and thus causes the succession of the seasons.

Rotation gives us the length of the day; *revolution* gives us the length of the year.

Different Kinds of Year.—A year is the period of the earth's revolution about the sun from a certain position back again to the same.

The **Sidereal Year** is the time taken by the sun in completing a revolution from a given star or other fixed point to the same star again. Its length is 365·256 mean solar days. The sidereal year is the time of the true orbital revolution of the earth.

The **Tropical or Equinoctial Year** is the time which the sun takes to pass from vernal equinox to vernal equinox again. As the vernal equinox advances 50·2″ each year to meet the sun, the tropical year is about 20 minutes shorter than the sidereal year. Its length is 365·242 mean solar days.

For ordinary purposes a year containing a fraction of a day would be inconvenient, and so the *civil year*, or the *year* of the calendar, is some whole number of days, generally 365 days, which is rather less than a tropical year. But we want the seasons, which are determined by the tropical year, to always occur at the same parts of the civil year, and therefore we try to bring these two years into agreement.

The difference amounts to nearly a quarter of a day, hence every four years we have a leap-year, containing 366 days, the ordinary years containing 365 days. But the difference is not quite a quarter of a day, and hence in 400 years we omit three of such leap-years, and make these ordinary years of 365 days. This makes the average length of the year almost exactly what it should be, viz. 365·2421 days. Therefore every year has 365 days, except every fourth year, which is such that its number is divisible by four, and this has 366 days, except again that those centuries which are not divisible by 400 have only 365 days. Thus 1884, 1864, 1840 were leap-years, and so were 1600, 1200, 800; but 1800, 1700 were not, and 1900 will not be a leap-year.

The **Anomalistic Year** has for its starting-point the perihelion of the earth's orbit, and is therefore the time between the two successive passages of the perihelion by the earth. As perihelion point moves eastward or backward each year about 11·25″, this year is nearly 5 minutes longer than the sidereal year. Its length is 365·259 mean solar days.

The relative magnitudes of the three kinds of astronomical year may be thus stated to the nearest second of mean solar time :—

Sidereal year = 360° = 365 d. 6 h. 9 m. 9 s.
Tropical year = 360° − 50·2″ = 365 d. 5 h. 48 m. 46 s.
Anomalistic year = 360° + 11·5″ = 365 d. 6 h. 13 m. 48 s.

318. **Effects of a Change of Angle between the Equator and the Ecliptic.**—Any change of this angle means, of course, a change of inclinanation in the earth's axis. If the earth's axis had been perpendicular to the plane of its orbit, the plane of its equator would have coincided with the plane of the ecliptic, day and night would have been of equal length at every place throughout the year, and there would have been no diversity of seasons. (The axis of the planet Jupiter is almost perpendicular to its orbit.) If the inclination of the earth's axis had been greater than it is, the sun would recede farther from the equator on the north side in summer, and farther on the south side in winter. A larger part of the earth would thus be in tropical regions and have the sun overhead twice a year, and a larger part would also be in arctic regions, with at least one day without any sunrise. Seasonal differences and changes in the length of the day would thus be increased. With an inclination of 45°, the tropical zones would extend 45° on each side of the equator, and the temperate zones would disappear, for the rest would be two arctic zones. Further increase of inclination would lead to an extension of the zones on each side of the equator where the sun would be overhead twice a year, and a further extension of the regions where the sun would remain above the horizon in summer and below the horizon in winter for one or more days. The great extremes of temperature in these latter regions would be very inimical to animal and vegetable life. Were the axis of the earth parallel to the plane of its orbit, the poles of the equator would be situated in the ecliptic ; the seasonal changes would be extreme, every part being in turn tropical and arctic.

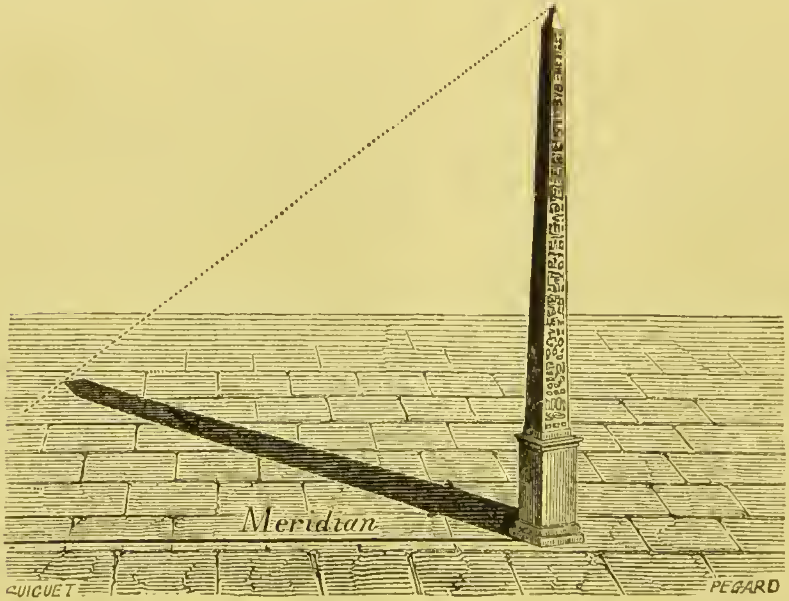

FIG. 202.—Egyptian Obelisk used as a Gnomon

CHAPTER XVII.

TELESCOPES—LIGHT, SUN, MOON, ECLIPSES—THE CELESTIAL GLOBE, ETC.

319. **The Telescope.**—The astronomer's chief instrument is the telescope. Two parts are necessary in every telescope: a lens or a mirror to collect the light and form a real image of the object looked at, and an eye-piece to examine and magnify this image. These two essential parts are enclosed in a tube, to shut out side rays.

The Astronomical or Refracting Telescope in its simplest form consists of a large double convex lens called the *object-glass*, and a smaller lens called the *eye-piece*. Fig. 203 represents the arrangement of the lenses and the paths of the rays of light in such a telescope. The rays from the distant object A B pass through the object-glass, and are so bent or refracted that the converging rays form an inverted image of the object at *a b*.

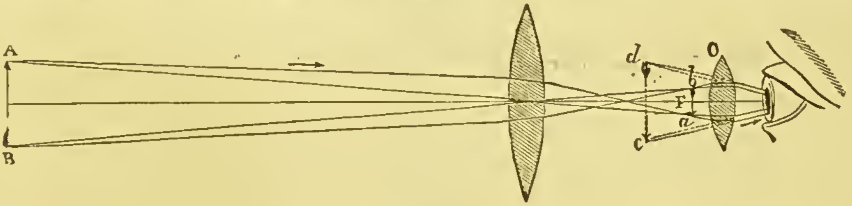

FIG. 203.

This image is examined through the eye-piece O, which acts as a magnifying glass, and forms an enlarged image of *a b* at *c d*. The *illuminating power* of a telescope depends on the area of the object-glass. If it is a thousand times greater than the area of the pupil of the eye, it collects a thousand times more light, and thus forms an image a thousand times brighter than the unaided eye would. Hence it enables us to see further into space, and brings into view objects invisible to the naked eye. But the brightness of the image is somewhat diminished by the light that is lost in passing through the lens, and it is further diminished by the eye-piece, which spreads the light over the magnified image that it forms of the first image; for the work of the eye-piece is to magnify the image formed by the object-glass, and this increase of apparent size, or magnification, virtually brings us nearer the object. The *magnifying power* of the eye-piece is measured by the increase in the width of the angle which is subtended at the eye by the image *c d* over that which is subtended by the object A B. It may also be estimated by dividing the focal length of the object-glass by the focal length of the eye-piece. The focus of a lens or mirror is the point in which the converged rays of light meet and are collected after being refracted or reflected. The focus of parallel rays is called the principal focus, and the distance of this point from the centre of the lens is called the focal length. If, then, the focal length of the object-glass be 60 inches, and that of the eye-piece be three-quarters of an inch, the magnifying power would be 80.

The object-glass of the astronomical telescope does not consist of a single lens as shown in fig. 203, as such a lens cannot bring all the rays which come from a point to a single focus. Accordingly the image formed by such a lens has coloured fringes. To get rid of this 'chromatic aberration,' as it is called, a compound lens, formed of two lenses of unequal dispersive materials, is used. Such an *achromatic* lens (Gr. *a*, not; *chroma*, colour) is shown in fig. 204. A is a concavo-convex lens of flint glass, and B a double convex lens of crown glass.

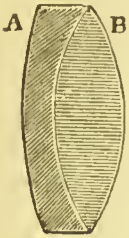

FIG. 204.

In all telescopes the tube containing the eye-piece is made to slide in the tube containing the object-glass, so that the eye can be brought to see the image at the distance of distinct vision. Fig. 205 shows a small telescope mounted on a pillar-and-claw stand, so as to be placed at any altitude and at any azimuth. A B is the tube containing the eye-piece at A. It can be made to slide in the tube C D by means of a milled screw-head at H. At D is the object-glass or objective.

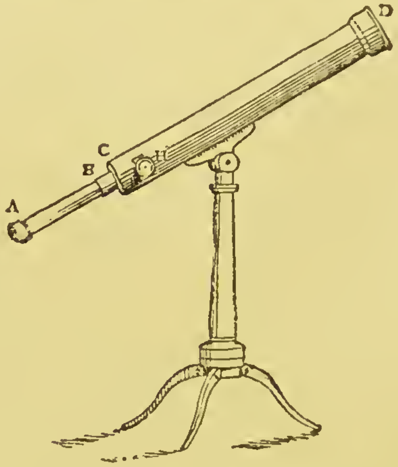

FIG. 205.—Small Telescope on pillar-and-claw stand.

Reflecting Telescope.—In a reflecting telescope a highly polished mirror takes the place of the object-glass in the refracting telescope.

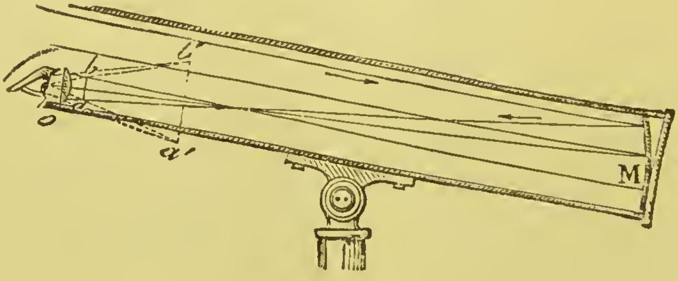

FIG. 206.

Herschel's form of reflecting telescope is shown in the figure. Rays of light from a distant object pass into a tube, at the further end of which a concave mirror M is placed. These rays are reflected by the mirror and form an image at *a b*. The mirror being slightly tilted throws the image to the side of the tube. By means of the eye-piece *o* this image is examined, and appears magnified at *a′ b′*.

320. **Reflection and Refraction of Light.**—Light is radiated from luminous bodies in straight lines. The rectilinear propagation of radiation is proved by our inability to see round a corner, by the fact that, if a number of similar objects be placed in a straight line, the nearest one hides the others, and by the forms of shadows corresponding exactly with that of the object as received from the light-giving body. From smooth polished surfaces, either plane or curved, light is thrown back or *reflected* in a regular manner. If the light falls upon a polished surface perpendicularly, it is reflected along the path through which it came; *if a ray strike a polished surface obliquely, it is reflected obliquely, and the angle of incidence is equal to the angle of reflection, and is in the same plane.*

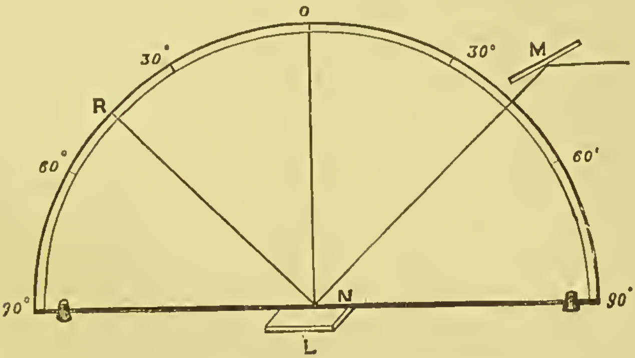

FIG. 207.—Reflection of a Ray of Light.

This law may be illustrated by a simple piece of apparatus. A card-board semicircle is divided into degrees. A piece of polished glass or bright metal, L, is placed at the centre, and a ray of light, M N, is deflected by a mirror, M, so as to meet the mirror at the foot of the perpendicular O N. It is then found to be reflected along N R, and the angle O N M will be found to contain the same number of degrees as O N R. A ray sent along O N is reflected along N O.

In *plane* mirrors the image of any object reflected appears to be as far behind the mirror as the object is in front of it, and the right and left hands are laterally inverted.

Curved mirrors also reflect light; and a concave spherical mirror reflects the light proceeding from every point of an object, so as to bring the rays together to a focus or point in front; and as every point of the object is thus reflected, an image of the object results. It is in this way that the image of a distant object is formed in Herschel's reflecting telescope (par. 319).

When light passes obliquely from one transparent medium (a medium is a substance through which rays pass, as air, water, glass) into another of different density, it is bent aside. This change of direction is termed the *refraction* of light. Passing from a rarer into a denser medium, it is bent towards the perpendicular from the surface of the denser medium. Thus L A, the incident ray from the candle L, on meeting the surface of the water, is bent in the direction A K, the angle of incidence, L A B, being unequal to the angle of refraction K A C; but for any two media the ratio of one angle to the other is regular. In more technical language, we may say that when a ray of light passes from one transparent medium to another, the *sine of the angle of incidence always bears a constant ratio to the sine of the angle of refraction.* The number expressing this ratio is called the *index of refraction;* from air to water the index of refraction is $\frac{4}{3}$, from air to flint glass $\frac{3}{2}$. Refraction explains the bent appearance of a stick partly immersed in water, as well as the visibility of a heavenly body for a short time after it has set. Lenses can be so formed that the light proceeding from the various points of an object through the lens is refracted and collected to corresponding points behind it, and thus a perfect image of the object is produced as just explained in speaking of the astronomical telescope. Further explanation of this will be given in the advanced course.

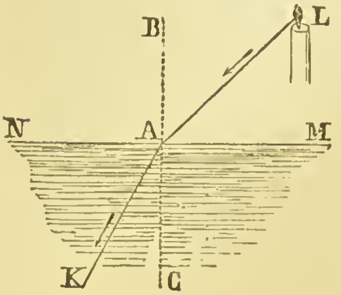

FIG. 208.—Refraction of Light.

321. **Analysis of White Light — The Spectrum.**—A wedge-shaped piece of glass, or other transparent substance, forming a solid, with two faces inclined to each other, forms a prism. In section such a solid appears as a triangle. If a ray of white light be passed through a prism, it is analyzed or decomposed into a luminous band of seven colours, termed a *prismatic spectrum.* These colours are red, orange, yellow, green, blue, indigo, and violet. This decomposition of white light into various colours is called the *dispersion* of light, and is caused by the unequal bending or refraction of the various rays that constitute white light. Let A B C represent the section of a prism of flint glass, and let P Q be a ray of white light passing into the prism. On entering the prism, it is refracted towards the broad base, whatever may be the position of the prism. One portion passes along Q R, and another portion along Q R′, other portions passing between these extremes. It is the red light that is least bent, and the violet suffers the greatest refraction; the intermediate rays of orange, yellow, green, blue, and indigo being refracted in this order between. On emerging from the prism into the air, the various rays are again refracted, and the spectrum S S′ may be received on a screen in a suitably darkened room. The visible spectrum, then, is the continuous band of colours observed when white light is passed through a prism, the action of the prism being

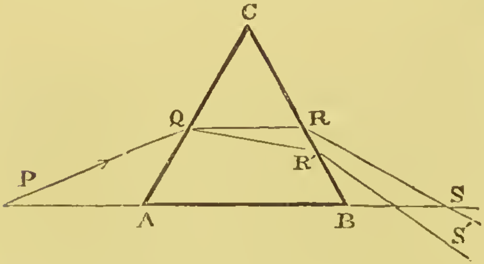

FIG. 209.—Action of Prism on Light.

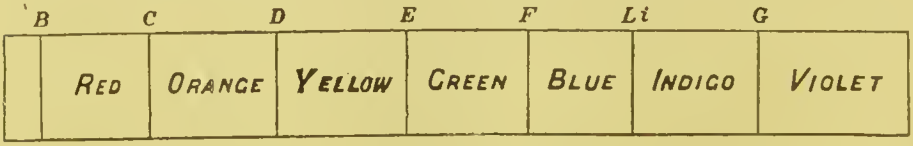

FIG. 210.—Diagram showing position of Colours in the Solar Spectrum.

to refract the different coloured rays forming white light unequally. These colours are usually given as seven, but they blend into one another gradually, and are really far more than seven. A diagram of the spectrum, even though uncoloured, will help to illustrate its nature. A coloured diagram may be seen in the Advanced Physiography.

We may here remark that the *solar* spectrum, obtained only by prismatic dispersion of sunlight, differs from the spectrum of a white-hot solid or liquid body in being crossed by certain fine black lines (often indicated by letters of the alphabet); but the explanation of these Fraunhofer lines, as they are called, does not belong to this stage.

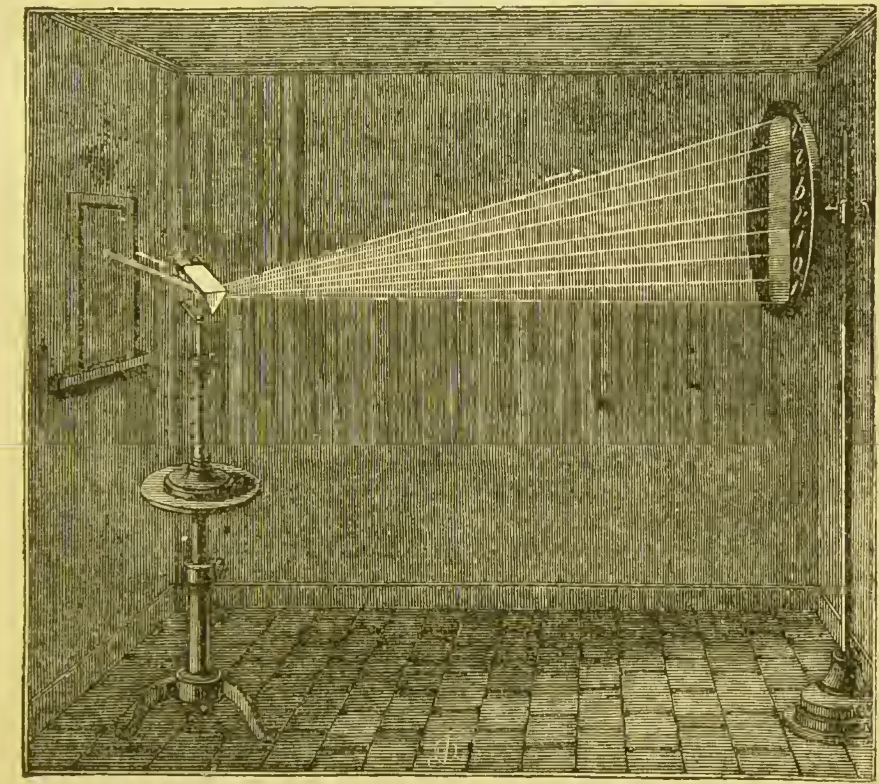

FIG. 211.—Decomposition of White Light into the Colours of the Spectrum by passing a beam of Sunlight through a Prism in a darkened room and receiving the Spectrum on a Screen.

That white light consists of a number of rays of different colours blended together is proved not only by the prismatic *analysis* of such light, but by the fact that these prismatic colours can be recombined to form white light. Thus, if a second similar prism be inverted and arranged with its faces parallel to the first, the light emerging from this second prism is no longer coloured, but the prismatic colours are synthetically recombined to form the compound colour white. Again, if a disc of white cardboard be painted in sectors of the prismatic colours in the same order and proportion as they occur in the spectrum, and then be made to revolve rapidly, the seven colours disappear and a greyish-white is seen. Newton's *colour-disc*, as such a disc is called, thus verifies the composition of white light by synthesis.

We have thus learnt: (1) that white light, or the light that gives the sensation of white, is not simple in composition, but a compound of the seven colours, red, orange, yellow, green, blue, indigo, and violet; (2) that white light can be analyzed by a prism into a coloured band or ribbon of light with these seven colours gradually passing into one another, and called the *visible spectrum*; (3) that the cause of separation is the different degrees of deviation which the different colours undergo by refraction; (4) that the red rays are least refrangible—orange, yellow, green, blue, indigo, and violet being the order of refrangibility of the others; (5) that the seven prismatic or rainbow colours can be recombined by synthesis, on using a second prism or a colour-disc, to form white.

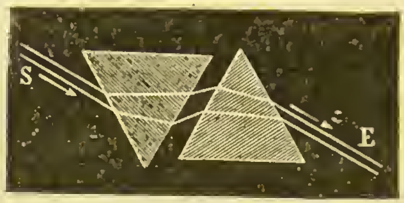

FIG. 212.—Showing how the prismatic colours may be recombined.

Light is now believed to consist of ether-waves (par. 45), radiated from a luminous body or other light source, the radiation being of the same kind as in heat, but of smaller wave-length. Different colours have different wave-lengths, the red being longest and the violet shortest, and white light containing all the wave-lengths of the spectral colours. Natural objects have different colours, because some of the ether-waves of sunlight are absorbed and others reflected or transmitted. Thus blue glass is blue because only the blue waves are transmitted while the other rays are absorbed. All rays travel with the same velocity, the velocity of light and radiant heat being 186,000 miles per second.

322. **The Sun—Its dimension, density, and attraction.**—The sun is an intensely hot self-luminous globe of enormous size, situated at a *mean* distance from the earth of about 92,800,000 miles. Knowing its distance, and measuring the angular diameter of its disc (par. 308), its real diameter is found by calculation to be 860,000, or nearly 110 times that of the earth. Since the volumes of spheres are in proportion to the *cubes* of their diameters, the sun's *volume* = $(110)^3 \times$ vol. of earth; that is, 1,331,000 times the volume of the earth. This means that the volume of the sun is so great, that were the earth placed in the centre of the sun, with its satellite the moon revolving round it at a distance of 238,000 miles, still the earth and the orbit of the moon together would reach but little beyond half-way to the circumference of the sun. Yet though the *volume* of the sun is 1,330,000 times that of the earth, its *mass*, or the quantity of matter contained in it, is only 330,000 times that of the earth. In other words, while it would take 1,330,000 globes as large as the earth to make a globe as *large* as the sun, yet it would only take 330,000 to make one as *heavy* as the sun. From this it follows that its *density*, or quantity of matter per unit of space, is only about *one-quarter* of the earth's density, as we find on dividing its mass compared with the earth by its volume compared

with the earth.[1] The force of gravity at the sun's surface is nearly twenty-eight times the force of gravity on the surface of the earth; and as the weight of a body is due to the force of gravity, a body at the surface of the sun would weigh twenty-eight times as much as upon the earth.

The physical condition of the sun is very different from that of the earth, though we know it is composed of very similar materials. The white hot surface that we see, called the *photosphere*, is believed to be largely a shell of highly heated metallic vapours surrounding the unseen mass beneath. Dark spaces seen in the photosphere are known as *sun-spots*, and these are often surrounded by brighter patches, termed *faculæ*. Above the photosphere a shallow envelope of gases, rising here and there into huge prominences, and known as the *chromosphere*, is seen in red tints when the

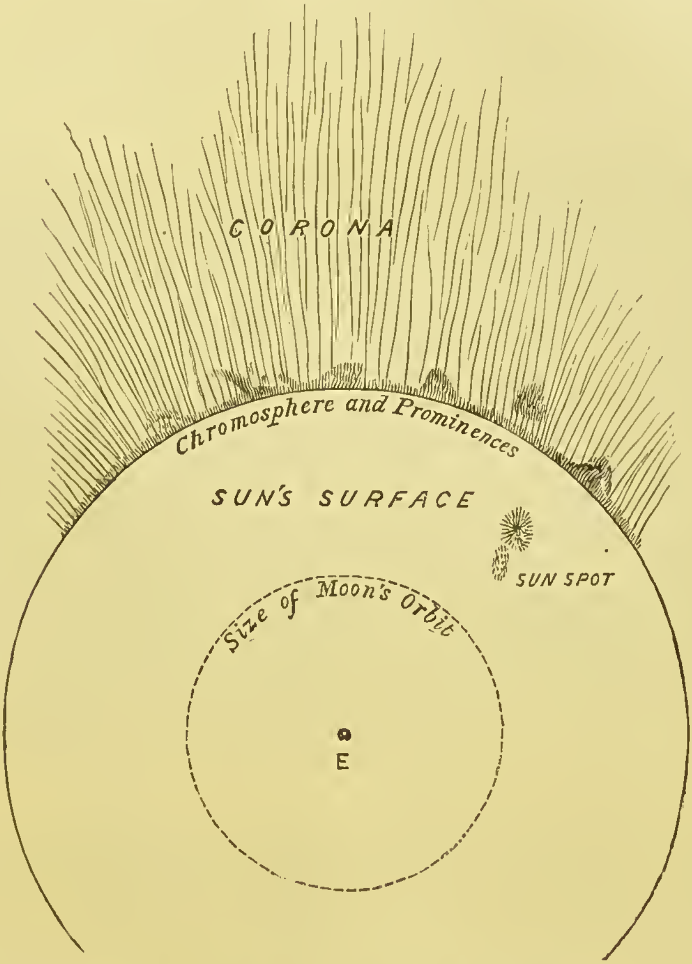

FIG. 213.—Comparative sizes of Sun and Earth.

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[1] The density of the earth compared with water—that is, its specific gravity—is 5·5; hence the specific gravity of the sun is only about 1·4.

sun is totally eclipsed. Beyond the chromosphere, there is also seen at the same time, a faint but far more extensive envelope called the *corona*.

The sun's rays supply light and heat not only to the earth, but also to the other planets which revolve round it. Its attraction confines these planets in their orbits and controls their motions. Kepler's three laws of planetary motion have already been given (par. 307). Kepler derived these laws from observation only, but Newton first *explained* them by showing that they were the necessary consequences of the laws of motion and the law of universal gravitation.[1] The centre of gravity of the *solar system* (as the sun with his attendant bodies is called), is the real point around which the planets revolve, but so enormous is the mass of the sun, that this point is situated not far from the sun's centre.

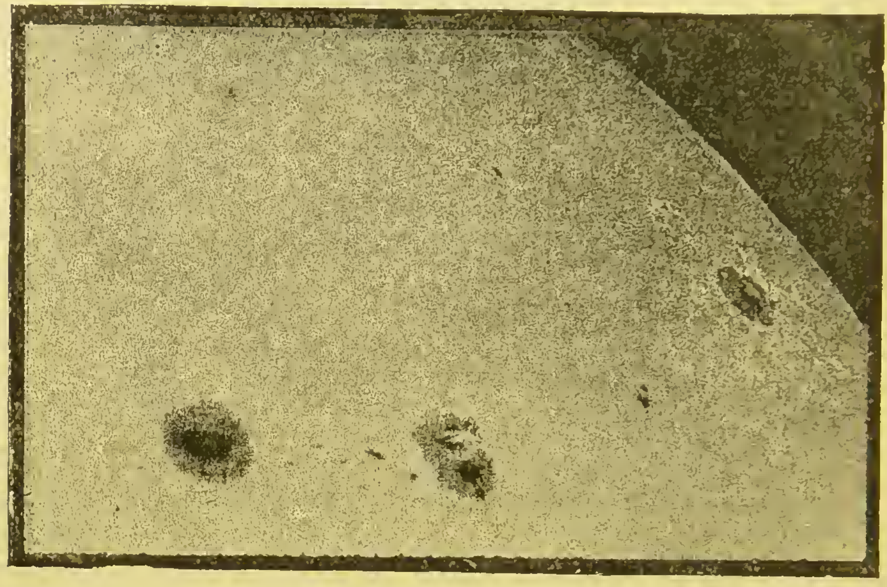

FIG. 214.—Part of Sun's Photosphere, with Sun-spots and Faculæ.

323. **The Moon.**—The moon is one of the secondary planets, or satellites, and it revolves round its primary the earth, while the latter is revolving round the sun. Its mean distance from the earth is only 238,000 miles. Though apparently as large as the sun owing to its nearness, its real diameter is only 2160 miles, and its volume, or bulk, only $\frac{1}{49}$ that of the earth. Its mass, or weight, is only $\frac{1}{80}$ that of the earth, and hence its density or compactness of matter is but a little more than $\frac{3}{5}$ that of the earth, and the force of gravity on its surface but $\frac{1}{6}$ that of the earth.

Besides its daily apparent motion from east to west, due to the daily rotation of the earth, it is easy to notice that it has an opposite motion, moving eastward among the fixed stars, in consequence of which it rises about 50 minutes later each night. A complete revolution of the moon round the heavens from one fixed star to the same fixed star is called a *sidereal* revolution and occupies 27 d. 7 h. 43 m.

The moon requires a longer interval to go through a revolution with respect to the sun, as the sun also moves eastward among the stars, though at a slower rate. Hence the *synodic* month, or the time occupied by the moon in passing from the sun round to the sun again, is longer than the *sidereal* month by more than two days. The mean value of the synodic month is 29·53 days, and this is the ordinary *lunar* month. *Calendar* months consist of a whole number of days—28, 30, or 31 as the case may be. In a year there are twelve calendar months, but thirteen lunar months.

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[1] See note, p. 324.

The moon's path among the stars is not situated in the same plane as the earth's path round the sun, for the moon's orbit is found to be inclined to the plane of the ecliptic at an angle of about 5°. The points at which the moon's orbit cuts the plane of the ecliptic are called the moon's *nodes* (see fig. 144).

When the moon in her orbit lies between the sun and the earth, she is said to be in *conjunction* with the sun; when the earth is between the moon and the sun, the moon is said to be in *opposition* to the sun. At either of the two points midway from conjunction and opposition, *i.e.* 90° from conjunction or opposition, the moon is said to be in *quadrature*.

The moon is an opaque, cold globe, covered with mountains, extinct volcanoes, and plains. She has neither water nor atmosphere, and always presents the same surface to the earth in consequence of rotating on her axis in the same time as she revolves round the earth. Moonlight is only reflected sunlight, the illuminated hemisphere being always turned towards the sun. When we see the whole lit-up side of the moon, she appears circular, and we say the moon is full. But we cannot see the whole of the illuminated hemisphere from the earth at all times. The various shapes this illuminated hemisphere assumes in the course of her journey round the

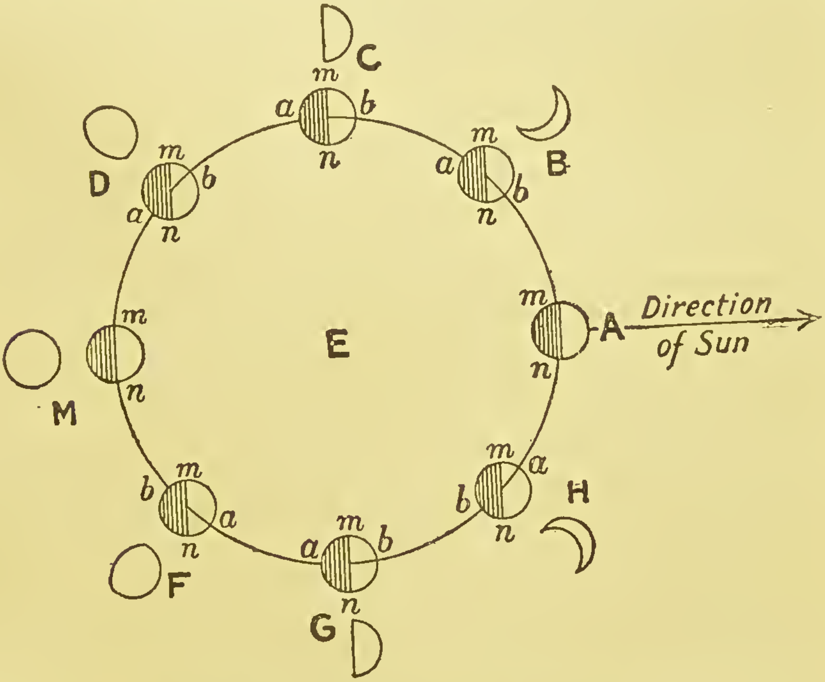

FIG. 215.—The figures upon the circle represent the chief positions of the Moon in its orbit. The outside figures show the different phases.

earth are called the *phases* of the moon. A figure will help us to understand these appearances, or *phases*, of the moon.

The figure represents the moon in eight different positions in her orbit round the earth, the sun being at an immense distance to the right. The line *m n* separates the illuminated half of the moon from the unilluminated half, and the line *a b* may be taken to separate the half of the moon turned towards the observer at E from that turned away from him.

At A the moon is in conjunction, being between the earth and the sun, and no portion of the illuminated half is visible. It is then said to be *new moon.*

At B, between four and five days afterwards, a small part of the lit-up surface is seen, and this appears as a thin *crescent* in the sky just after sunset.[1]

At C the moon is in quadrature, at her *first quarter*, and one half the lit-up hemisphere is seen by the observer ; so that the moon appears in the sky as a bright semicircle. It is *half-moon.*

At D more than half the lit-up hemisphere is seen, and the moon appears *gibbous* (Lat. *gibbus*, a hump) in the sky.

Before the end of 15 days the moon is in *opposition* to the sun at M, and the whole of the illuminated hemisphere is turned towards the observer, so that it is seen as a complete circular *disc* in the sky. It is now said to be *full moon.*

After full moon, the moon becomes gibbous again, F ; in a few more days it is again half-moon at the *third* or *last quarter*, G ; and as it gets towards the sun, more and more of the dark side turns towards us, so that the crescent H grows narrower and narrower, until it disappears at new moon again.

It is worthy of note that the moon is higher in the heavens and longer above the horizon in the winter than in summer. This is owing to the plane of its orbit being at night high towards the south in winter and low in summer, as is the ecliptic.

The moon's orbit, like that of other planets, is elliptical, but irregular. When nearest to the earth, she is said to be in *perigee;* when at the greatest distance, in *apogee.*

324. **Eclipses, Lunar and Solar.**—Since light proceeds in straight lines, part of the space behind any opaque body is shut off from the light in front of it, and the space thus darkened is termed a shadow. Both the spherical earth and the moon cast conical shadows into the space behind opposite to the sun, and any body lit up by the sun entering one of these shadows becomes invisible, or is eclipsed.

An eclipse of the *moon* is caused whenever it passes into the shadow-cone cast by the earth. This can only happen with the moon full, *i.e.* in opposition ; for at no other time is the earth between the sun and the moon. If the moon's orbit were in the same plane or level as the earth's orbit, a lunar eclipse (Lat. *luna*, the moon) would occur every month at full moon ; but owing to the inclination of the planes of the two orbits (fig. 144) being about 5°, the moon may be to the north of the ecliptic or below to the south of the ecliptic at the time of opposition, and then the earth's shadow-cone misses the moon. If the moon, however, is at or near one of her *nodes* when in opposition to the sun, it must pass more or less into the earth's shadow; for the centres of the sun, earth, and moon are then in, or nearly in, the same plane, and the earth's shadow always reaches far beyond the greatest distance of the moon. Thus the two conditions for a lunar eclipse are—

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[1] When the moon is a crescent a portion of the dark side is often faintly visible, owing to sunlight reflected upon it from the earth.

(1) The moon must be in opposition, *i.e.* full.

(2) The moon must be at, or near, one of her nodes.

Lunar eclipses are of two kinds—*total* when the whole surface of the moon passes into the earth's shadow, and *partial* when only a part of the moon's surface passes into shade.

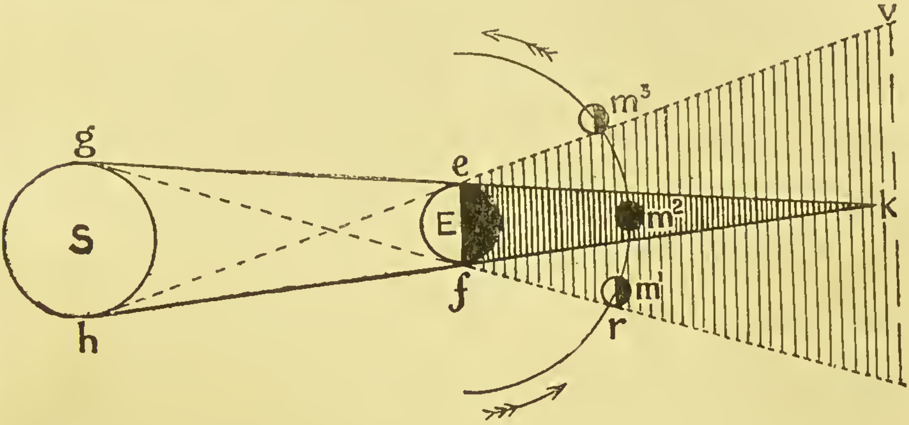

FIG. 216.—Eclipse of the Moon when in the shadow of the Earth.

Fig. 216 illustrates a total eclipse of the moon when she is in opposition at one of her nodes, and all three bodies are supposed to be in one and the same plane—the plane of the page. S represents the sun, E the earth, and m different positions of the moon in her orbit about the time of opposition. By drawing lines from g and h, the upper and lower edges or limbs of the sun, through e and f, the upper and lower points of the earth, and continuing these lines till they meet at k, we determine the dark cone-shadow, or *umbra*, in which *all* the sun's light is cut off by the earth. By drawing the other lines, $h\ e\ v$ and $g\ f\ p$, from the upper and lower points of the sun through the opposite points of the earth, we find two spaces in which only a part of the sun's rays are cut off by the earth, and where, therefore, there is only a faint shadow called the *penumbra*.

A lunar eclipse begins with the first contact with the penumbra, though there is but little darkening till it enters the umbra. As the moon's eastern limb enters the umbra, a part of the surface seems cut off, and in the case of a total eclipse the visible portion gets smaller and smaller till the whole disc passes into the shadow. A lunar eclipse will be total only when the moon is very near a node at the time of opposition, so that its course lies nearly through the centre of the umbra, and it may then last more than $1\frac{3}{4}$ hours. In many lunar eclipses the moon is so far from a node that it passes above or below the centre of the umbra, and a part is in the shadow and a part outside, the eclipse being partial.

Lunar eclipses are visible in the whole of that hemisphere of the earth which is turned towards the moon at the time, those inhabitants seeing the whole of the eclipse who have the moon above the horizon while the eclipse

In many cases of total eclipse the moon is still visible as a dull red or copper-coloured disc. This is owing to a small portion of sunlight being bent or refracted into the shadow by the earth's atmosphere.

An eclipse of the *sun* is seen whenever the moon's shadow-cone falls upon the earth. This can only happen at new moon, *i.e.* with the moon in conjunction. A *solar* eclipse, however, does not occur at every conjunction, on account of the inclination of the moon's orbit to the plane of the ecliptic. But if the moon should pass through either node at or near the time of conjunction, in certain parts of the earth the sun may be wholly or partially eclipsed. Thus the two conditions for a solar eclipse are—

(1) The moon must be in conjunction, *i.e.* new.

(2) The moon must be at or near one of her nodes.

Solar eclipses are of three kinds—*total*, *partial*, and *annular*.

The moon's umbra is only a little longer than her distance from the earth when the moon is nearest or in perigee, and the width of the shadow where it meets the earth seldom exceeds 150 miles. Hence only a small part of the earth can be in *total* darkness at any time. With the moon in apogee, the shadow does not reach the earth, and only the central part of the sun can be eclipsed to observers in the shadow-cone produced; so that a ring of the sun is still visible round the central dark portion, and the eclipse is annular (Lat. *annulus*, a ring). We can illustrate the phenomena of solar eclipses by figures.

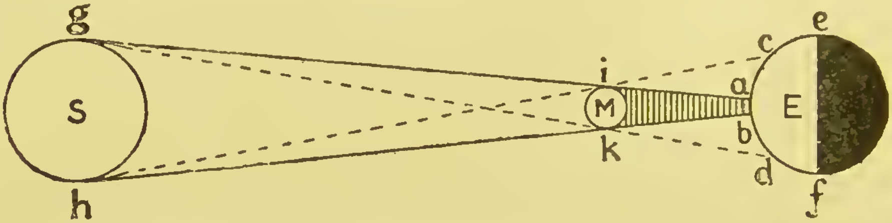

FIG. 217.—Eclipse of the Sun (Total in certain parts), the shadow of the Moon falling on the Earth.

In fig. 217 let S indicate the sun, E the earth, and M the moon at conjunction, with the moon at a node and in perigee. The dark shadow-cone, or umbra, determined by drawing the tangent lines *g i* and *h k*, fall upon the earth's surface at *a b*. Within this space only is there a *total* eclipse of

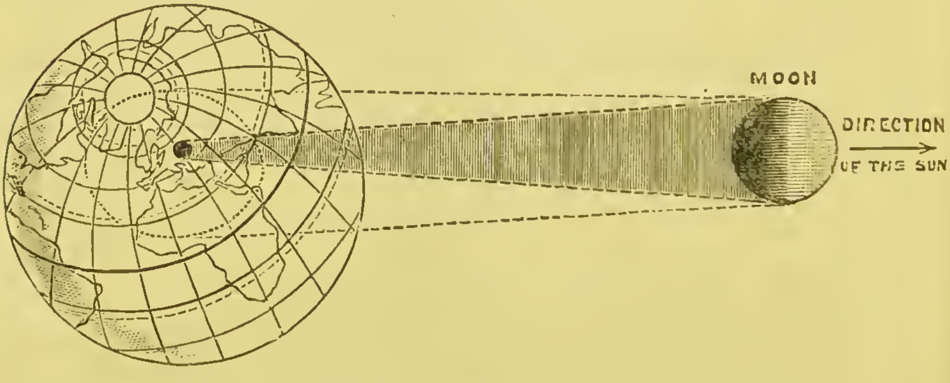

FIG. 218.—Lunar Cone-Shadow, showing where the Solar Eclipse is Total.

the sun, the eclipse beginning on the western limb of the sun. Between *a* and *c* there will be a partial eclipse of the sun, its lower portion being invisible; and between *b* and *d* there will also be a partial eclipse of the upper portion of the sun, both these portions being in penumbra. From *c* to *e* and from *d* to *f* no eclipse is visible, nor is any eclipse seen in the shaded part of the earth where it is night.

As already remarked, a solar eclipse is total to but a small portion of the earth, the breadth of the shadow-cone covering but a small space (averaging from 130 to 160 miles), as illustrated by figs. 217 and 218. The duration of totality at any one place is small, varying from a few seconds to nearly 8 minutes, for the earth's rotation carries every place eastward much faster than the moon moves eastward, and thus the shadow-cone sweeps over a narrow belt of the earth until it passes from it.

To illustrate the conditions of an annular solar eclipse, consider fig. 219, where the moon at a node and in conjunction is supposed to be in apogee or at her greatest distance from the earth. In this case her apparent diameter is less than that of the sun, and the dark shadow falls short of the earth, reaching only to *b*. Between the points *a* and *b*, where the shadow-cone produced meets the earth, the central parts of the sun are covered by the moon, and the outer portion of the sun is seen as a ring or *annulus* of light. Here the eclipse is *annular*. From *a* to *c* and from *b* to *d* a *partial* eclipse is visible. Beyond *c* and *d* no eclipse takes place.

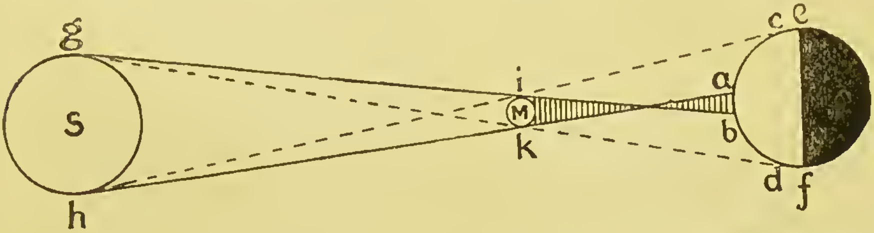

FIG. 219.—Annular Eclipse of the Sun, the shadow of the Moon not reaching the Earth.

There cannot be an annular eclipse of the moon, for the earth's shadow where it meets the moon is always greater in breadth than the diameter of the moon.

A total or annular eclipse of the sun is a rare occurrence at any particular place. No total eclipse of the sun will be visible in England until June 29, 1927, though one will be visible in Norway on Aug. 9, 1896. Astronomers eagerly examine these phenomena in order to study the chromosphere and corona surrounding the sun's bright photosphere, for it is only during a total eclipse that these phenomena become visible.

Bearing in mind the conditions of lunar and solar eclipses, we can understand that, although the moon passes through a node about twenty-five times a year, it usually happens that she is not then in the same line as the earth and the sun, and that consequently eclipses do not happen as often. The greatest possible number that can happen in a year is seven—five solar and two lunar; the least possible number is two, both solar. But though solar eclipses are more numerous than lunar eclipses, it is not so with those visible at a given place. For a solar eclipse can only be seen by people who happen to be on the narrow track described by the moon's shadow across the earth, while a lunar eclipse is visible over the whole hemisphere that has the moon above the horizon during the eclipse.

325. **Atmospheric Refraction.**—This is the bending of a ray of light proceeding from a celestial body through the ether of space after passing into the atmosphere of the earth. Suppose the inner circle of the figure to represent the earth, and let the concentric circles represent layers of the atmosphere, each layer being of greater density than the one outside it. Were there no atmosphere, a ray of light from the heavenly body S′ would proceed in a straight line to an observer at A, and he would see it in the direction of A S′. But the atmosphere causes a deflection, so that a ray that proceeds from S suffers refraction in each layer, and really follows the curved track S *a b c* A. The actual direction of the ray as it reaches the observer is A X, and at X the observer sees the star. The angle X A S is the angle of refraction, and the nearer the object is to the horizon, the greater is this angle. At the zenith, Z, there is no refraction. The effect of atmospheric refraction is, therefore, to increase the altitude of a celestial object. As the effect of refraction is to elevate heavenly bodies a little more than half a degree when they are on the horizon, the sun (or moon) appears just above the horizon when it is in reality just below it. In this way three or four minutes are added to the length of daylight both morning and evening. Even after the sun has set, or before it rises, it still shines on the clouds and the air above us. The *reflection* (not *refraction*) of this light produces the phenomenon known as *twilight*.

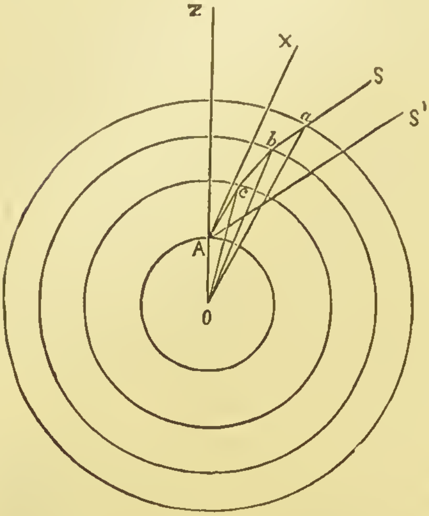

FIG. 220.

Atmospheric refraction is only a special instance of a general law which states that a ray of light, on passing from a rarer to a denser medium, is always refracted towards the perpendicular to the surface (par. 320).

326. **Parallax.**—If we look at a distant object through a window, we may often notice that it is directly in a line with some mark on the window. If now we change our position to the right or left, the object will no longer appear behind the same mark, and the greater our base of movement, the greater will be the apparent displacement of the distant object. Moreover, for the same change of position, the less will be the displacement, the more distant the object observed is. This apparent displacement of an object observed, but due to a real change of position of the observer, is called the *parallax* of that object; and the angle whose vertex is at the centre of the object observed, while its sides pass through the two points of observation, is called the *parallactic angle*, or angle of parallax. In astronomy, the parallax of a heavenly body is the angle between two lines drawn to it, one from the observer's position, and one from the centre of the earth; for it is agreed in astronomy to refer all observations to the centre of the earth, and to regard the *true* position of a heavenly body as the position it would occupy when seen from the centre of the earth. By the help of a figure and a little consideration, it will easily be understood that the nearer an object is to the zenith, the less will be its parallax, and the more distant an object is, the less will be the angle of parallax. An object will have

the largest parallax when it is on the horizon. The *equatorial horizontal parallax* of a heavenly body is the angle at the centre of a heavenly body subtended by an equatorial radius of the earth. In the figure the angle

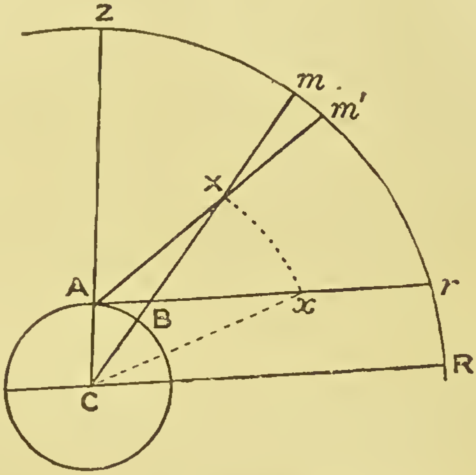

FIG. 221.

A X C or its arc mm' on the distant celestial sphere R Z is the observed *parallax* of the heavenly body X; the angle A x C is its (equatorial) *horizontal parallax*. The fixed stars have no horizontal parallax, owing to their immense distance. But it is by finding the parallax of the moon that *its distance* is determined. This is effected as follows:—With suitable instruments, observations at two stations, A and B, having the same longitude are made, and the angle A X C, which is the parallax of the moon, is found. Angle A C X, the difference in latitude of the two stations, is also known. The base A C, which is the earth's radius, is also known. Hence, knowing two angles and one side of the triangle A X C, we can find C X, the distance of the moon.

The sun's distance is also determined by finding its parallax, but this is effected by the aid of a transit of Venus. Having found its parallax, its distance from the earth can be estimated. The moon's equatorial horizontal parallax is 57′ 3″; the sun's only 8·8″.

327. **The Vernier.**—The length of any object is usually found by reading off the number of divisions on a scale applied to the object, while angles are measured by reading off the number of degrees and subdivisions of a

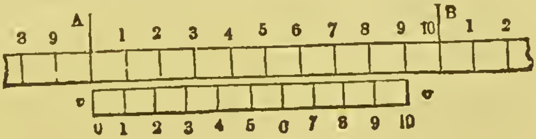

FIG. 222.

degree in a certain arc. Greater accuracy can be obtained by the use of a *vernier*. This is a small graduated scale or arc made to slide along the larger fixed scale or arc, so as to enable us to read the position of an index lying between the graduations of the larger fixed scale. Let A B be a portion of the larger fixed scale representing an inch, and subdivided into tenths; *v v* is the vernier or small scale made to slide along the larger scale.

Nine divisions of the fixed scale equal ten divisions of the vernier. Hence one division of the vernier is equal to nine-tenths of a division of the larger scale, so that each part of the vernier is less than a part of the fixed scale by $\frac{1}{10}$, *i.e.* by $\frac{1}{10}$ of $\frac{1}{10}$ (or $\frac{1}{100}$) of an inch. With this scale and vernier we can therefore read to hundredths of an inch.

'Suppose, for example, the position of the vernier with respect to the scale to be as represented in the annexed figure, where the zero of the vernier is brought to coincide with a certain point *p* on the scale. The point *p* is read on the scale 29 inches, $\frac{2}{10}$, and a fraction which is to be measured by the vernier. Here the division 6 on the vernier coincides with that which is marked 8 on the scale, therefore the distance of the zero of the vernier from the last division 2 behind it on the scale is $\frac{6}{100}$ of an inch; for as 6 on the vernier coincides with 8 on the scale, the distance of 5 from 7 is $\frac{1}{100}$; of 4 from 6, $\frac{2}{100}$; of 3 from 5, $\frac{3}{100}$; of 2 from 4, $\frac{4}{100}$; or 1 from 3, $\frac{5}{100}$; and of 0 from 2, $\frac{6}{100}$. In like manner, if the vernier were pushed along till the division 8 coincided with 30 inches on the scale, then the reading of the zero point would be 29 inches $\frac{2}{10}$ and $\frac{8}{100}$.' A vernier scale has usually one graduation more than the corresponding portion of the other scale, *and the number of its divisions gives the fractional part of the small divisions of the larger scale to which we can read.* If the number of divisions of the vernier be 20, the different divisions of the vernier will be $\frac{1}{20}$ the divisions of the scale. In the barometer the divisions of the scale are twentieths of an inch, and by taking a vernier divided into twenty-five parts, and made equal in length to twenty-four of the divisions of the scale, we can read to $\frac{1}{25}$ of $\frac{1}{20}$, or $\frac{1}{500}$ of an inch. In the same way we can ascertain small fractions of degrees on a circle. The figure shows a circle divided into degrees, and into parts of 6′, or tenths of a degree. Suppose

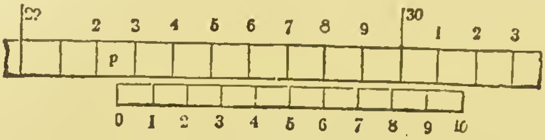

FIG. 223.

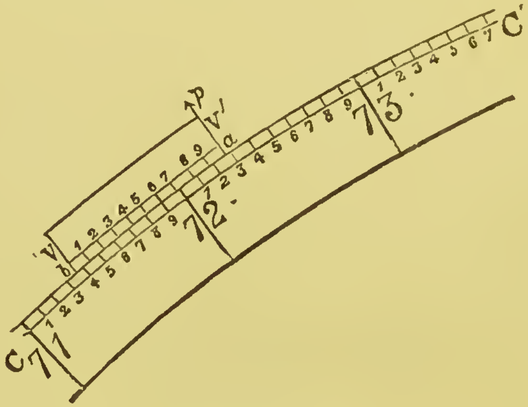

FIG. 224.

we wish to ascertain the position of the point *p*. The vernier *v v'*, divided into equal parts, measures exactly nine of the divisions of the arc *c c'*, and thus enables us to read to $\frac{1}{10}$ of $\frac{1}{10}$ of a degree, *i.e.* to 6″ of arc. On moving the vernier to the point *p*, we see that on the graduated circle the reading is 72° 2 tenths (or 72° 12′) and a fraction to be found by the vernier. On careful examination, we see that the sixth division of the vernier coincides with one of the divisions of the arc. Hence the fraction we have to add to the above reading is 6 hundredths, and the position of the point *p* is exactly 72° 2 tenths 6 hundredths, or 72·26°, or 72° 15′ 36″.

328. **Equation of Time.**—The word 'equation' in astronomy has at times a meaning different from that it has in algebra. In this phrase it means the quantity of time which is to be added to or subtracted from true solar time to get mean solar time. True or apparent solar time is obtained by finding the exact moment of the transit of the sun's centre across the observer's meridian; it is the time also which appears on the sundial. Mean solar time is furnished by a good clock. Hence we may say—

Dial time ± equation of time = clock time.

We have already pointed out (par. 309) that the length of the true solar day is greater than the length of a sidereal day, and we have also stated that true solar days vary in length for two reasons.

(1) The eccentricity of the earth's orbit, as already explained, causes the angular motion of the earth round the sun, that is, the distance of the orbit traversed in a day to be greater the nearer the earth is to the sun. Thus the earth does not move the same distance each day to bring the same meridian opposite the sun (fig. 179), and hence the solar days are longer than the average when the earth is near perihelion, and shorter than the average when the earth is at aphelion. The average or mean solar day is 3 minutes 56 seconds longer than the sidereal day, but in December it is 4 minutes 4 seconds longer, and in June only 3 minutes 48 seconds longer.

(2) The obliquity of the ecliptic is the second and chief cause of inequality in the length of the solar days. The ecliptic along which the sun moves is inclined to the equator, so that even if the sun moved uniformly along the ecliptic, the solar days would be unequal, for equal intervals along the ecliptic are not represented by equal intervals along the equator or between the meridians, and solar time, to be regular, must be measured by equal arcs along the equator, as our eastern rotation occurs in the plane of the equator. Near the equinoxes the sun's daily motion is on the hypothenuse of a right-angled triangle, while the earth's eastern motion to overtake him is along the base parallel to the equator. Thus the solar days about the equinoxes are about 20 seconds shorter than the average. At the solstices the sun moves in the tropics a short time on a *small* circle parallel to the great circle, the equator, and its average distance along this small circle is more in angular measure than the same distance on the equator. Hence about the solstices the obliquity of the ecliptic makes the solar days longer than the average.

As the true solar days are thus unequal, and a clock cannot be regulated to keep true solar time, and yet the business of daily life is governed by the rising and setting of the sun, astronomers imagine a *mean* sun that moves uniformly along the equator, and which is never far on one side or other of the real sun. This mean sun keeps mean solar time, and it is mean noon at any place when the mean sun crosses the meridian of that place. Greenwich mean time (G.M.T.) is the time as regulated by two successive transits of the mean sun across the meridian of Greenwich. A mean solar day is divided into 24 mean solar hours, and these are subdivided into minutes and seconds. These are the hours and minutes of a good clock and of ordinary life.

It will now be readily understood that the mean sun will sometimes be in advance of the true sun and sometimes behind it. Sometimes the two causes of inequality act together, and sometimes one acts against the other. The small differences between the true solar day and the mean solar day accumulate for a time, then grow less, and four times a year the two measures of time coincide. Thus on September 1 the mean and apparent noon coincide; but, the true solar day being now shorter than the mean solar day, the sun passes the meridian before mean noon on the next day, still earlier on the day after this, and so on, until November 3, when the sun is sixteen minutes before the clock keeping mean time. After November 3 the true solar day gets longer than the mean solar day, and the difference between the sun and the clock gets smaller and smaller until on December 25 the two times again agree and both noons occur at the same instant. It is this difference of time between the real sun and the mean sun that is called the 'equation of time,' and astronomers require it in order to regulate the mean-time clock. The equation of time is given in certain almanacs for every day in the year, but it is sufficient to give here the dates on which the equation of time vanishes and the dates on which it has its greatest value, to the nearest minute.

February 11	true sun	15 minutes slow.
April 16	,,	correct.
May 14	,,	4 minutes fast.
June 15	,,	correct.
July 26	,,	6 minutes slow.
September 1	,,	correct.
November 3	,,	16 minutes fast.
December 25	,,	correct.

The equation of time is *positive* if the sun is 'after the clock,' that is, if the true sun transits after the mean sun. The equation of time is negative if the sun is 'before the clock,' that is, if the true sun transits before the mean sun.

One of the effects of the equation of time is to make the interval from sunrise to noon, as given in the almanacs, usually unequal to that between noon and sunset. Forenoon and afternoon are not of the same length, for the noon of the almanac is *mean noon.* Thus, when the sun is fast, he passes the meridian before mean noon, and the forenoon is longer than the afternoon. When the sun is slow, or after the clock, he does not pass the meridian until after mean noon, and afternoon is longer than forenoon.[1] And thus we see why the afternoon light appears to last longer and the sun to rise later some time after Christmas than at the corresponding time before Christmas. Of course, the true sun always crosses the meridian at a moment that divides the time from sunrise to sunset into two equal parts.

A figure is subjoined to show graphically the value of the equation of time at different parts of the year. In the upper part of the figure the value due to the earth's varying speed in its orbit and the value due to the obliquity of the ecliptic are shown separately.

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[1] On Feb. 11 mean noon is 15 minutes before true noon, and therefore the forenoon is shortened and the afternoon lengthened by this amount, *i.e.* the afternoon is 30 minutes longer than the forenoon. On Nov. 3 the forenoon is 32 minutes longer than the afternoon. In fact, the lengths of the morning and afternoon always differ by *twice the equation of time.*

The horizontal line divided into twelve parts to represent the months is the zero line, and the distance of the curves above or below the lines gives the positive or negative values of the equation of time according to the scale of minutes on the left. The curve C C C C represents the part of the equation of time due to unequal velocity, and it shows that the maximum value due to this cause is about 7 minutes, and that the quantity vanishes twice a year under this influence alone. The curve B B B B represents the part of the equation of time due to the inclination of the ecliptic to the equator, and it shows that the maximum value due to this cause is about 10 minutes, the quantity vanishing four times a year.

The two causes sometimes act in the same direction and sometimes in opposite directions. Their combined effect is shown in the curve D D D D, and from this curve the value of the proper equation of time may be estimated approximately, the exact value for every day being given in the Nautical Almanac. As an example of the use of this almanac, suppose that the true sun be observed on the meridian of Greenwich on a certain day. It is then true noon. On looking at the date in the almanac, we find the equation at that date to be 4 m. 17 s., and this is 'to be added to apparent time.' The mean time at the instant of observation is therefore 0 h. 4 m. 17 s., and this is the time the mean-time clock should indicate.

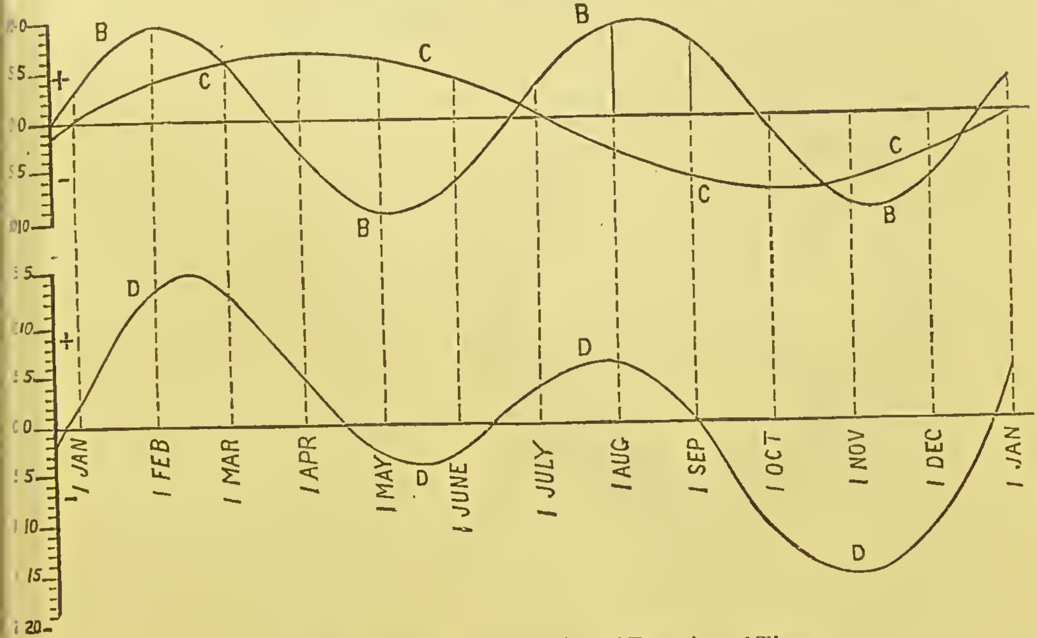

FIG. 225.—Graphic representation of Equation of Time.

329. **The Celestial Globe.**—The celestial globe is a ball mounted in a framework, and upon it are drawn the circles of the celestial sphere and a map of the stars. A wooden ring going round the globe represents the rational horizon, a celestial object being visible if it be on that part of the globe above the plane of this horizon. The meridian is represented by a vertical brazen graduated circle, and the globe turns on an axis, the ends of which are the poles. Such a globe may be used to illustrate the daily motions of the heavenly bodies, as well as other astronomical phenomena.

To use the globe, however, we must set it for the particular latitude where we wish to note these motions. To do this, it is necessary to elevate its north pole to an angle above its horizon equal to the observer's latitude, for we have learnt that the altitude of the pole above the horizon is always equal to the latitude of the observer. Having set the globe, we shall see, on turning the globe round its axis, the path of any particular star, and be able to note the extent of its circuit above the horizon. Thus if the pole of the globe be elevated 90° so as to point to the zenith, we shall represent the situation of an observer at the north pole, and the stars will be seen to describe circles parallel to the horizon. If now we place the poles of the globe in the horizon, we are able to understand the position of an observer at the equator, for on turning the globe all the stars will be seen to describe circles perpendicular to the horizon, the circles diminishing in size as we pass from the equator to either pole. When the pole of the globe is elevated to $51\frac{1}{2}°$, we see the motion of the stars as an observer at London does.

We may also use the celestial globe to represent the various diurnal courses of the sun at different latitudes, and thus to examine the variations in the length of day and night. In fig. 226 the globe is set for the latitude of London, the arc H P being $51\frac{1}{2}°$. The same wooden ring H F H represents the horizon, and the meridian is represented by the brazen ring H Z M passing through the zenith Z and the pole P, and this meridian meets the horizon at right angles. A great circle drawn perpendicular to the polar axis, of which one half, F E G, is above the horizon, represents the celestial equator, or equinoctial, and this meets the horizon at the east and west points, F and G. The observer is at O. By turning the globe on its axis P Q, it will be seen that when the sun is on the equator (a small piece of paper may be gummed on in position to represent the sun) it will in the course of one revolution be above the horizon for half its path and below the horizon for another half, rising exactly east and setting exactly west. Day and night are thus seen to be equal when the sun is on the equator. Now, the sun's yearly path is on the ecliptic, the line crossing the parallel circles in the figure, and this crosses the equator only at the vernal and autumnal equinoxes. After March 21 the sun passes north of the equator, and its diurnal path ceases to be a great circle and becomes a small circle parallel to the equator, the dimensions of which gradually decrease until it reaches a declination $23\frac{1}{2}°$ (more exactly 23° 27′) north of

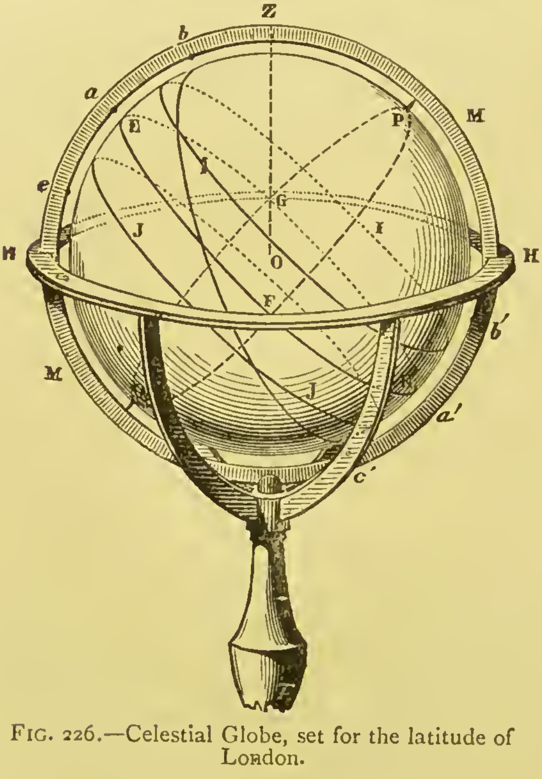

FIG. 226.—Celestial Globe, set for the latitude of London.

the equator on June 21, the date of the summer solstice. The point *b* indicates the position of the summer solstice, the arc *a b* being 23½°. The small circle I I represents the daily path of the sun at a date between March 21 and June 21, and it is plain that the part of this circle above the plane of the horizon is greater than the part below it. Hence the length of day exceeds that of night. Moreover, the rising point of the sun when his daily path is on the small circle I I is to the north of the east point F, its culmination on the meridian is above the point of culmination when on the equator, and its setting-point is to the north of the west point G. Increase in the sun's northern declination thus increases in the Northern Hemisphere the length of the day and the noonday altitude of the sun, and increase in noonday altitude means a diminution in the zenith distance. Change of declination also causes the sun's amplitude of rising and setting to change. A small circle parallel to I I and passing from *b* to *b′* would represent the sun's daily path when its declination is at a maximum, and when, therefore, those quantities that increase with increase of declination north are at a maximum. After the summer solstice the sun begins, in his movement on the ecliptic (see fig. 182), to return to the equator, which he reaches again on September 22, the autumnal equinox, when the days and nights are again equal. After September 22 the sun's southern declination increases; his daily path becomes a small circle of the celestial sphere parallel to the plane of the equator and to the south of it. This circle decreases in size until the winter solstice is reached, December 22. The diurnal path of the sun on a day between the autumnal equinox and the winter solstice is represented by the small circle J J. It is easy to see that the greater part of this circle is below the plane of the horizon, and that when the sun is on this circle day must be shorter than night, the altitude of the noonday sun must be less than at the equinox, and that when the sun is below the equator he rises to the south of east and sets to the south of west. A small circle parallel to J J and passing from *c* to *c′* would represent the sun's daily path when its southern declination is at a minimum, and when, therefore, the days are shortest and the midday altitude least. From December 22 the sun passes back towards the equator and a series of changes in the relative lengths of the days and nights is repeated in inverse order, until, when the sun reaches the vernal equinox in the course of 365¼ days, the cycle of changes is complete. By elevating the pole to a greater

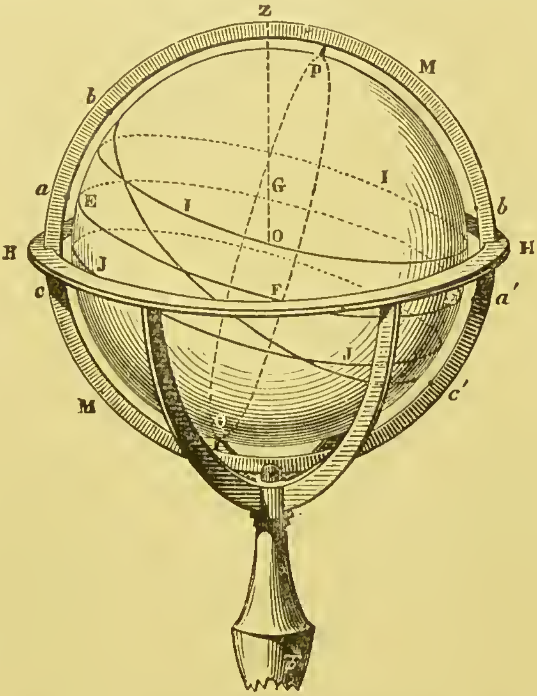

Fig. 227.—Celestial Globe, set for latitude 75° N.

height above the horizon, we shall find that the portion of the sun's daily path above the horizon after he leaves the vernal equinox increases with increase of latitude, until, at an elevation of 66½°, the sun at the summer solstice would just skirt the northern horizon at midnight, so that the longest day at this latitude would be 24 hours. At the winter solstice the sun at noon would only just reach the horizon, so that the shortest day would be a day without the sun.

Going to a still higher latitude, as 75° N., where the pole is only 15° from the zenith. we should find that the sun in his daily path after the vernal equinox remained still longer above the horizon each day, and as his declination gradually increased, the whole of the diurnal path day after day for 103 days would be above the horizon. Fig. 227 shows a globe set for a northern latitude of 75°. When the sun is on the equator at this latitude, as at any other latitude north of the equator, he rises in the east, sets in the west, and day and night are equal. But as he passes northward in his path along the ecliptic, the portion of his daily path that appears above the horizon rapidly increases, and soon the whole of the path day after day is above the horizon. Thus in the figure the small circle I I, representing his daily path as before at a date intermediate between the vernal equinox and the summer solstice, only just reaches the horizon. At a latitude of 75° N. a little calculation will show that, after a declination of 15° N. is reached, the whole of the sun's daily path will be above the horizon until the sun attains its maximum declination 23½° N., and returns again to that of 15° N. It will be noted that the greatest noonday altitude of the sun at this latitude is only 15° + 23½° = 38½°. Thus is explained the phenomenon of the midnight sun within the Arctic Circle. The decrease in the length of day and night as the sun passes south of the equator, and the continuous darkness of winter for many days at this latitude will be readily understood. Passing to the north pole itself, we should there find the sun's daily path to be in small circles exactly parallel to the horizon. The sun at the summer solstice would perform his daily circuit of the heavens in a circle always 23½° above the horizon, at the equinoxes his path would be on the horizon, and at the winter solstice his path would be on a circle 23½° below the horizon (see fig. 186). The path at intermediate dates can be easily realized.

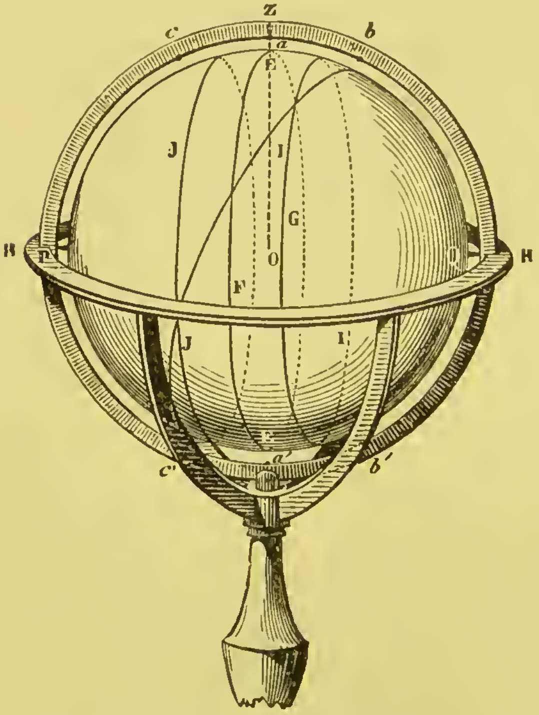

Fig. 228.

Passing to the extreme of this, to the equator, an observer there would see the sun perform his daily path in vertical circles perpendicular to the plane of the horizon. Fig. 228 shows a globe set for latitude 0°. Day and night would always be equal, as one half of the sun's daily path would always be above the horizon, and one half always below. The sun would be twice in the zenith. At midsummer he would have a zenith distance of 23½° north of the equator, and at the midwinter a zenith distance of 23½° south of the equator. The amplitude of his rising and setting points would vary to the same extent. We add a table giving the number of days during which the sun does not set in summer nor rise in winter at various latitudes in the Northern Hemisphere :—

North Latitude.	Sun does not set for about	Sun does not rise for about
66° 33′	1 day	1 day
70	65 days	60 days
75	103 ,,	97 ,,
80	134 ,,	127 ,,
85	161 ,,	153 ,,
90	186 ,,	179 ,,

The difference between the number of days on which the sun never sets and the number on which he does not rise is accounted for by the fact that he takes about seven days longer to move through the portion of his yearly path north of the equator than he takes to move through the portion south of the equator (par. 317).

We may also remark that in speaking of the length of day at different latitudes, no account is taken of refraction (par. 325). At the horizon the mean refraction is about 33′, and the effect of this is to accelerate the time of sunrise and to retard the time of sunset. As the mean apparent diameter of the sun is about 32′, the sun appears to be just above the horizon when in reality it is just below.

330. **The Sundial.**—In speaking of the sundial (par. 295), we stated that the *style* or *gnomon*, which is usually a rod or the edge of a thin plate of metal, must be parallel to the earth's axis. It must, therefore, point to the celestial pole, and make an angle with the horizontal dial-plate equal to the latitude of the place. At London this angle will be 51½° ; at Edinburgh, 56° ; and thus a dial serviceable at one latitude will be of no use at a different latitude. Since the daily apparent motion of the sun due to the earth's rotation appears to carry it round the earth's axis in 24 hours, the sun also appears to travel round the style of the dial, and it thus casts the shadow of the style upon the side of the dial away from the sun. At noon, when the sun is on the meridian of the place of observation, the shadow will be cast exactly north. As the sun appears to move through 15° each hour, the position of other hour-lines on the dial-plate may be found by marking the position of the shadow at the end of each movement of the sun through 15°. The graduations that mark the hours on a dial-plate are not at equal intervals, as the horizontal plane of a plate is not perpendicular to the earth's axis, except at the poles.

The difference between sundial time and mean clock time is sufficiently explained in pars. 309 and 328.

APPENDIX.

(*To be taken in connection with Chapter II.*)

PRINCIPLES OF MECHANICS, NOTES, ETC.

331. **Force, Weight, Mass.**—We have already said that *force* is any cause which changes or tends to change a body's state of rest or motion, and that *mass* is the quantity of matter contained in a body (par. 14). Now just as the unit of length is an arbitrary distance chosen for convenience (a *foot* in the English system, a *metre* in the metric system), so the unit of mass is an arbitrary quantity of matter. In the English system this unit of mass is the pound avoirdupois containing 7000 grains; in the metric system it is the mass of one cubic centimetre of water at its maximum density, and is called a gram. But the word 'pound' is used in two senses, and this leads to confusion unless it is carefully noted. Sometimes the word 'pound' is used for the force of the earth's attraction on a body, *i.e.* the weight of a body (par. 13); sometimes the word is used for the quantity of matter contained in a body. Now since the force of gravitation varies inversely with the square of the distance (par. 20), it is plain that the weight of a body becomes less when taken farther from the earth's centre, greater when brought nearer. Hence the weight of a body is greater at the poles than at the equator (par. 18); less on the top of a tower than at the foot. But the mass or quantity of matter is the same in each case. Hence there is a distinction between a mass of one pound, which is an invariable quantity of matter, and a weight of one pound, which is a force varying in amount according to its distance from the centre of the earth (par. 17). Still, we may compare the masses of two bodies by comparing their weights under the same conditions as mass is proportional to weight.

332. **Momentum.**—*Momentum*, or Quantity of Motion, denotes the product of the mass of a moving body into the velocity with which it moves. We may take as the unit of momentum a body of 1 lb. which is moving with a uniform velocity of 1 foot in 1 second. Then the numerical value of the momentum of a body is the product of the number of pounds in it by the number of units of velocity with which it is moving. Experiment shows that when force produces motion in a body, the momentum produced in one second is proportional to the force. Hence force can be measured by the momentum it is capable of producing in a unit of time. A ball of lead weighing 10 lbs. and moving with a velocity of 18 feet a second would strike an obstacle with the same force as a ball weighing 30 lbs. and moving with a velocity of 6 feet a second. The momentum or mass-velocity in both cases equals 180.

Thus momentum = mass × velocity, and the momentum produced by a force is exactly proportional to the force, so that force can be measured by the momentum it produces. Further, when several forces act upon a body, each produces motion in its own direction.

333. **Composition of Forces.**—We often wish to know what effect two or more forces have upon a body, and thus to find out what single force will produce the same result as all the others combined. This single force is called the *resultant*, and the problem of finding it is known as the *Composition of Forces.*

I. If the forces act in the *same* direction on a point in a body, their resultant will be the *sum* of the magnitudes of the forces, and will act in the same direction as the forces, since each force produces its own effect, *e.g.* the resultant force applied to a waggon drawn by a team of horses is the sum of the individual efforts of each horse.

II. If *two* forces act in exactly *opposite* directions on a point in a body, their resultant will be the (arithmetical) *difference* of the magnitudes of the forces, and will act in the direction of the greater force. Thus if a man is rowing a boat up a stream with a certain force, he will either propel the boat forward, or will drift back, according as the force he exerts on the boat is greater or less than that of the stream, and the rate of progress will be the difference between the speed due to the current and that due to the force exerted by the rower. Thus, if the rate of the stream is two miles an hour, and the rate of the boat due to the force exerted by the man be five miles an hour, the resultant force on the boat will be equivalent to a rate of three (5 − 2) miles per hour. If the forces are equal and act in exactly opposite directions, the body upon which they act will have no tendency to move. It is then said to be in *equilibrium.*

(If there are more than two forces acting in opposite directions, it is obvious from what has been said that their resultant can be found by summing up all the forces acting in the one direction, and all the forces acting in the other, and then finding the resultant of these two forces.)

III. When the forces act at an angle to each other, the magnitude and direction of their resultant is not so readily seen.

Let us consider first the case of *two* forces, one of 12 lbs. and the other of 35 lbs., acting upon a point O of a body in directions making an angle of 90°. Now we can represent a force exactly by a straight line, the length of the line being proportional to the force and its direction indicating the line of action.

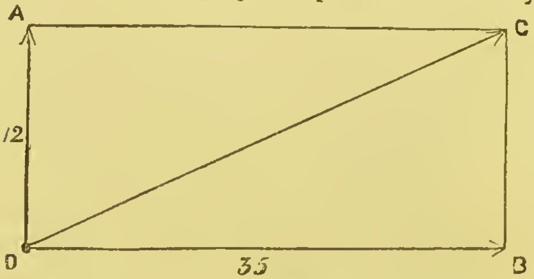

FIG. 229.

Draw therefore two lines at right angles to each other through the given point O. Then take any scale, *e.g.* $\frac{1}{12}$ inch to represent a lb., and set off 35 divisions along one line, and 12 divisions along the other. Using O B and O A as adjacent sides, and completing the parallelogram O B C A, we find the diagonal O C represents, both in magnitude and direction, the resultant of the forces acting at O. Its numerical value is got from the scale, and its direction by actual measurement of the angle. We should find it to be in this case a force of 37 lbs. acting at an angle of 30° to the direction of the larger force.

This theorem is true for all angles, and is known as the *parallelogram* *of forces*, being often stated thus :—*If two forces acting at a point be represented in magnitude and direction by the two adjacent sides of a parallelogram, then their resultant or conjoint effect is represented both in magnitude and direction by that diagonal of the parallelogram which passes through the point.*

By means of this proposition we can find the resultant of any number of forces acting at a point by taking any two of the forces, finding their resultant, then finding the resultant of the first resultant and another force ; and so on, until we get the final resultant of all the forces.

IV. If the forces act in a *parallel* direction, their resultant is their sum, if acting in the same direction, but is equal to their difference if acting in opposite directions. The method of finding the point at which it acts is shown in books treating of mechanics.

334. **Resolution of Forces.**—Just as several forces acting upon a point may be composed into one resultant, so one force may be divided into several others called its 'components,' which combined together are equivalent to it.

This is done by means of the parallelogram of forces. For if we represent, as we can do, the original force by a straight line, we can regard this line as the diagonal of a parallelogram whose sides we are trying to find. But round one diagonal any number of parallelograms can be placed, and to determine the magnitude of two components we must know the directions they are to have so as to fix which of these parallelograms is the one we must take ; or *vice versâ*, to determine the direction of the components, we must know their magnitudes.

It is usually convenient, however, to determine the horizontal and vertical components of a force ; that is to say, to determine them when the angle between the two component forces is a right angle.

Thus, suppose a man is pulling a block of stone along the ground by means of a rope passing from the stone to his hand. Now all the force exerted by the man is not used in dragging the stone. If, however, we 'resolve' the force into its horizontal and vertical components by means of the parallelogram of forces we can find by comparing on the same scale the length of the line representing the original force with those representing the components, what portion of the force exerted by the man is used in dragging the stone along, and what portion tends to lift the stone.

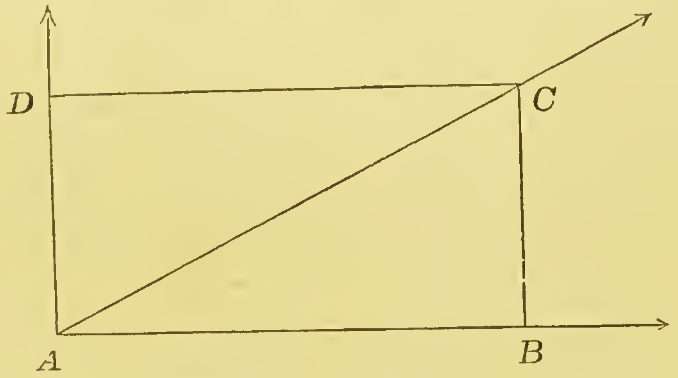

FIG. 230.

Suppose the force exerted by the man is equal to a weight of 50 lbs.

acting at an angle of 30° to the horizon. Letting 1 inch represent 25 lbs., draw a line, A B, 2 inches long, and then draw the parallelogram with its adjacent sides at right angles. This will give the vertical and horizontal components of the force, the former, A D, in this case being represented by a line 1 inch long, and the latter, A B, by a line $\sqrt{3}$ inches long. Hence we learn that a force equal to a weight of 25 $\sqrt{3}$ lbs. is being spent in moving the stone onward, and one of 25 lbs. in tending to raise it upward.

By inclining the rope at various angles to the ground, and determining the components in each case on completing the parallelogram, the student can find out for himself what effect the inclination of the rope has upon the relative magnitudes of the components, and thus prove why less force is required to drag the stone, the more the direction of the force is parallel to the direction of motion of the stone.

Other examples of the resolution of a force into its components are afforded by the towing of a boat by a person on the bank of the stream, and the action of the wind in raising a kite or in blowing a ship along, even in a direction nearly opposite to its own.

335. **Parallelogram of Velocities.**—Just as one force can be found which is the combined effect of two other forces, so the resultant of two or more simultaneous velocities may be found.

A velocity, like a force, can be represented by a straight line, its direction being represented by the direction of the line, and its magnitude by the length of the line. Therefore, '*if a body have given to it at the same time two velocities, which can be represented by the two sides of a parallelogram, then will the resultant velocity be also represented in magnitude and direction by the diagonal drawn through the point of application.*'

Consider the case of a stone dropped from a balloon which is sailing through the air horizontally. Just before being let go, the stone has only one velocity, viz. that of the balloon, but on being released the force of gravity imparts another velocity to the stone. If A B represent the horizontal velocity of the stone, and A C the vertical velocity, on completing the parallelogram, the diagonal A D will represent the resultant velocity, though the continuous action of gravity in reality causes the stone to describe the curved path indicated.

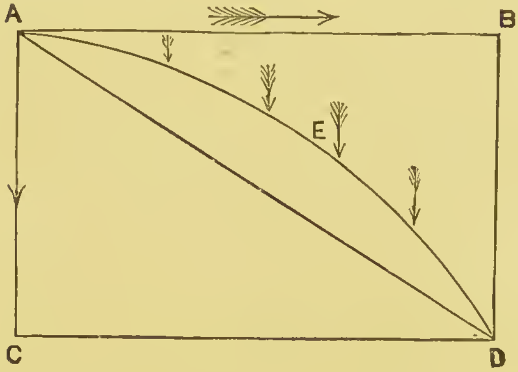

FIG. 231.

336. **Conversion of Rectilinear into Circular Motion.**—When a body is moving in a straight line, the motion is termed *rectilinear*; when a body moves in a curve, the motion is termed *curvilinear*, or if the curve be equidistant from a fixed point, *circular*.

Newton's first law of motion (par. 12), shows that when a body is once put in motion, it will continue to move in a straight line with uniform speed unless acted upon by some force. Hence in every case of curvilinear motion, there must be a force deflecting the moving body from a rectilinear path. If a body is moving *uniformly* in any other path than a straight line, some force must be continuously deviating it from a straight line. Consider the case of a stone swung round in a circle at the end of a string.

If the string should break, the stone will move off in a straight line along a tangent to the circle at whatever point in the circle the stone happened to be. The force that converts this rectilinear motion into a circular motion, or the force which compels the stone to describe a circle, is called the *centripetal force* (Lat. *peto*, I seek), because it is a force seeking or acting towards the centre of the circle. This force is constant in magnitude, and being always at right angles to the direction of the moving body, neither accelerates nor retards it.

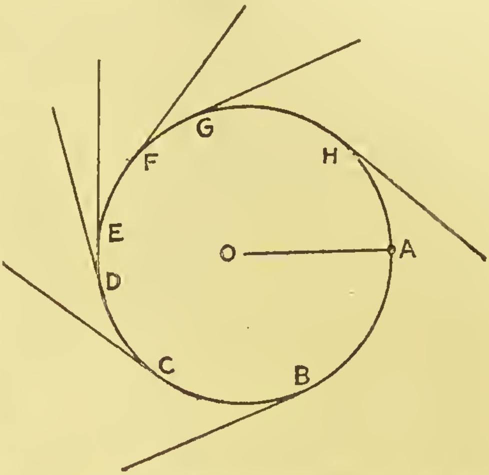

FIG. 232.—Showing how a stone whirled in a circle would fly off at a tangent if suddenly released.

The rectilinear motion of a body may therefore be converted into circular motion by a force acting continuously upon the body at right angles to its natural rectilinear path. For uniform circular motion, the value of this centripetal force is represented by the formula $f = \frac{mv^2}{r}$, where m is the mass or weight of the body, v the velocity, and r the radius, *i.e.* the force varies directly as the mass of the body multiplied by the square of the velocity. This shows that when a stone is whirled round by a string, the larger the stone, or the quicker it whirls, the greater is the centripetal force. The force exerted by the hand drawing the stone towards the centre, and causing the tension in the string, is this centripetal force. There is of course (par. 32, note) the reaction of the stone upon the string, which is equal and opposite, and this is sometimes spoken of as *centrifugal force* (Lat. *fugio*, I flee). The tendency of the stone, however, is not to move *outwards* from the centre, but in a straight line tangential to the circle, in consequence of its inertia, and it is only turned from its natural straight path by the central force pulling it into a circular path.

Examples of centripetal force may be found in astronomy. The moon's motion is due to a combination of two velocities, revolving round the earth in an orbit nearly circular because deflected from a natural rectilinear path by a centripetal force, viz. the earth's gravitative attraction. In fact, Newton showed that its path may be regarded as compounded of an original impulse in a rectilinear direction, and a constant pull—the force of gravitation—towards the earth's centre, and that generally, were a planet projected with a certain velocity in a direction at right angles to the radius connecting the planet and the sun, the planet would for ever describe a circle round the sun.

It is easy to understand that some modification of this velocity or direction of projection may lead to other closed curves than a circle, *e.g.* an ellipse, and the law of gravitation, according to which the force of attraction varies inversely as the square of the distance, combined with a certain specific initial impulse has been proved to explain the elliptical paths of the planets, and their varying velocity in different parts of the orbit (fig. 176).

337. **Machines and the Mechanical Powers.**—Energy is the power of

doing work (par. 39). In many cases it is inconvenient or not practicable to apply the energy to do work directly.

A contrivance for transferring energy in such a manner that it may be applied advantageously or conveniently is called a *machine.*

The source from which the energy is derived is called the *power,* the body which receives it being called the *resistance* or *weight.*

Of course it must be borne in mind that energy, like matter, cannot be created, and therefore that no increase in the quantity is ever effected by any machine. It merely transforms it or alters its point of application.

Amount of work done, or amount of energy spent, is measured in mechanics by the product of the resistance overcome into the distance through which it is overcome. Thus by lifting a weight of 1 lb. 6 feet high, I do the same amount of work as lifting a weight of 6 lbs. 1 foot high, the amount done being in both cases 6 units of work, or 6 foot-pounds, the unit of work being the work done in raising 1 lb. 1 foot high. Now most machines are contrivances by means of which a small power moving through a large space is enabled to move a large resistance through a small space. Hence, if we disregard the friction [1] between the parts of the machine, we have—

$$\text{Power} \times \text{its space} = \text{weight or resistance} \times \text{its space}.$$

This principle is sometimes expressed by saying that—

'What is gained in power is lost in speed,'

since the power has to pass through a larger space than the resistance, if a small power is to move a large resistance.

The Mechanical Advantage of a machine is the ratio of the weight to the power, and may be obtained by dividing the space moved through by the power by that moved through by the weight or resistance, *e.g.* in using a crowbar, if the end where the power is applied is moved through 2 feet, whilst the other end, placed under a block of stone, moves through 3 inches, the mechanical advantage

$$= \frac{2 \text{ feet}}{3 \text{ inches}} = \frac{24}{3} = 8,$$

i.e. a pressure of 20 lbs. would lift a block of stone 20 × 8, *i.e.* 160 lbs. in weight, though exactly the same amount of work, viz. 40 foot-pounds, has been done at each end of the bar.

The Mechanical Powers.—All machines, however complicated, are composed of the so-called mechanical powers, each one of which may be regarded as a typical machine. The ones with which we are concerned are the lever, the pulley, the inclined plane, and the screw.

338. **The Lever.**—A lever is a rigid bar or rod resting upon and capable of motion about a fixed support or axis called the *fulcrum.* The power and the resistance are applied at various points of this rod.

There are three different kinds or orders of levers, according to the relative positions of the fulcrum, the power, and the resistance.

---

[1] *Friction.*—In actual use, the power required for working a machine is always greater than it should be if we calculate it from the strict mechanical advantage. This is due to the fact that a certain amount of the power is used up, not in overcoming the resistance or weight, but in overcoming the surface rubbing or friction between the various parts of the machine.

If the *fulcrum* is in the middle, *i.e.* between the power and the weight, the lever is said to be of the *first order or kind.* A crowbar, an ordinary balance, a steelyard, a boy's 'see-saw,' are examples of the first kind of lever, a pair of scissors being a double lever of this class.

In a lever of the *second kind*, the *weight* is between the power and the fulcrum, as in the case of a wheelbarrow or a gate on its hinges. A pair of nutcrackers is an example of a double lever of this kind.

In a lever of the *third kind, the power* is in the middle, *i.e.* between the fulcrum and the resistance, as, *e.g.*, in a pair of tongs or a pair of shears for cutting grass.

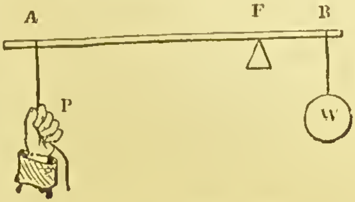

FIG. 233.—First order.
(Fulcrum in the middle.)

A lever may be regarded as composed of two parts, called *the arms*, the lengths of which are measured from the fulcrum. Thus, the distance from the power to the fulcrum is one arm (sometimes called the power arm), and that from the resistance to the fulcrum the other arm (resistance arm); and *power multiplied by its arm is equal to weight multiplied by its arm;* and this rule may be called *the principle of the lever.*

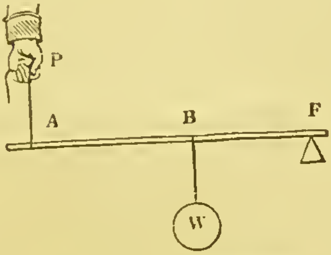

FIG. 234.—Second order.
(Weight in the middle.)

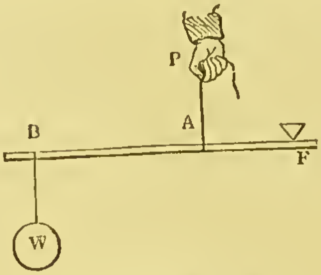

FIG. 235.—Third order.
(Power in the middle.)

In calculating the mechanical advantage of a lever, we may consider the lengths of the arms instead of the distances moved through by the power and resistance, for it is obvious that the latter are dependent on the former. Thus, if the power arm is twice as long as the resistance arm, the power will move through twice as much space as the resistance when the lever is in use. In the case of a lever, therefore, we may say that

$$\text{the mechanical advantage} = \frac{\text{length of the power arm}}{\text{length of the resistance arm}}$$

e.g. in a lever of the first order, which we will suppose is used to raise a stone (fig. 236), the distance of the power from the fulcrum is 5 feet, and that of the resistance is 1 foot. What power would be required to move a weight of 40 lbs.?

$$\text{Here mechanical advantage} = \frac{5 \text{ feet}}{1 \text{ foot}} = 5$$

i.e. a power of 1 lb. would move a weight of 5 lbs.; therefore to move a weight of 40 lbs. a power of $\frac{40}{5}$, *i.e.* 8 lbs., would be required.

In a lever of the first kind there may or may not be a mechanical advantage; in a lever of the second kind there must be a mechanical advantage, since the power is always further from the fulcrum than the resistance; whilst in a lever of the third kind we get a *mechanical disadvantage*, since the resistance is at the end, and therefore moves through a greater space than the power.

Hence, in this case, the power will always have to be greater than the resistance; and levers of this kind are, consequently, only used where it is

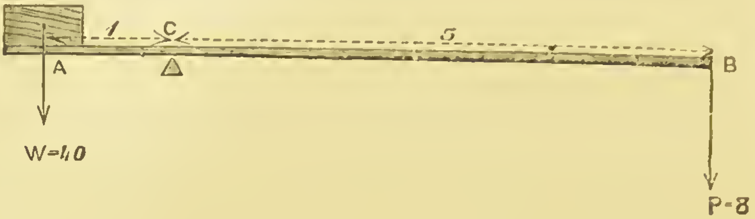

FIG. 236.

required to move a small weight through a large space, and where plenty of power is available.

In actual use, the weight of the lever, which we have neglected here, would have to be taken into account.

339. **The Pulley.**—A pulley is a wheel having a grooved circumference or edge, and turning freely in a frame-work called the block. In the groove a cord is placed, to one end of which the power is attached.

Pulleys are of two kinds—*fixed pulleys* and *movable pulleys*.

A fixed pulley is one which is attached to some stationary support, such as a beam, so that the pulley, as a whole, does not change its position. On the other hand, a *movable pulley* is one which, as the weights are raised or lowered, changes its position.

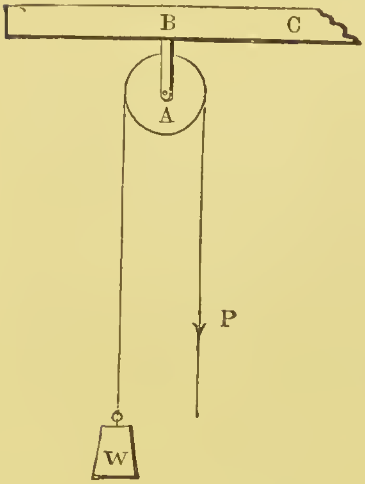

FIG. 237.—Fixed Pulley.

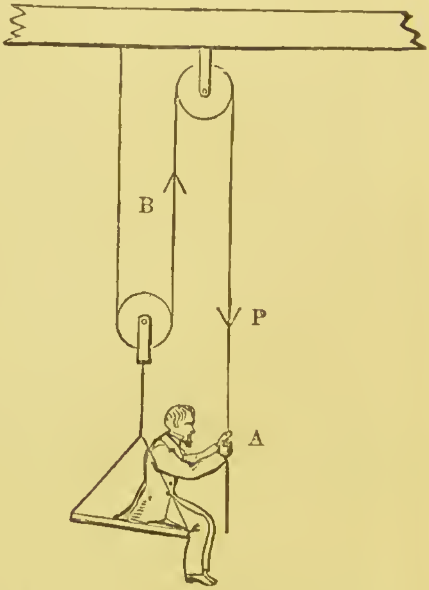

FIG. 238.—Single Movable Pulley.

Fixed pulleys are used to alter the direction of the applied force, and give no mechanical advantage. A man, to lift a weight, must exert force in an upward direction, but with the help of a fixed pulley he can apply it much more conveniently downwards. Since, however, the power and the resistance always move through the same space, there is no mechanical advantage, and the force required to raise the weight is the same whether a fixed pulley is used or not.

A movable pulley is itself attached to the resistance, the cord passing round it being fastened at one end to some fixed support, whilst to the other end the power is applied (*vide* fig. 238). The end of the cord to which the power is applied is often led over a fixed pulley, simply for the sake of convenience.

A little thought (or, better still, a little practice with a movable pulley) will enable the student to see that to raise the resistance one inch the power must pass through two inches; or, more generally, the power passes through twice as much space as the resistance. Hence *the mechanical advantage of one movable pulley is two* (*vide* fig. 238); that is, with the aid of this pulley a man could lift a hundredweight by applying a force equal to the weight of 56 lbs. Two movable pulleys give an advantage of four, and so on.

Several pulleys are often combined together in various ways, so as to increase the mechanical advantage, forming what are known as the various systems of pulleys, but for a further account of these the reader is referred to books on mechanics.

We have neglected the weight of the pulley and its block, because they are usually so small when compared to the other forces acting; and they may thus be regarded as weightless pulleys.

Again, we have assumed that our pulleys work without friction, so that the tension of a string which passes round a pulley is the same on each side of it. Allowing for these two small errors, what has been stated above actually occurs.

340. **The Inclined Plane.**—This mechanical power consists of a plane or smooth surface inclined to the horizontal at a certain angle, known as the *angle of inclination.*

The distance from the bottom to the top up the slope is called *the length* of the plane; the face on which it rests, *the base;* the vertical face, *the height.*

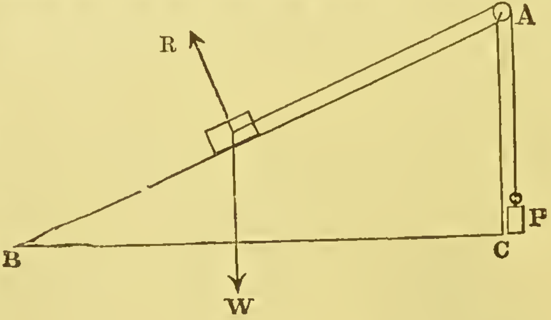

FIG. 239.

The work done in drawing a weight from the bottom to the top of the plane along its length will be equal to the product of the resistance or weight into the height of the plane, since when it is at the top it has only been lifted through a vertical height equal to that of the plane. But the power has then moved through a distance equal to the length of the plane.

$$\text{Now mechanical advantage} = \frac{\text{distance moved through by power}}{\text{distance moved through by resistance}}$$

$$i.e. = \frac{\text{length of plane}}{\text{height of plane}}$$

If, therefore, the length of the plane is 2 feet, and the height is 1 foot, the mechanical advantage is 2 feet, *i.e.* a weight of 20 lbs. could be drawn up the plane by a power equal to the weight of 10 lbs.

A road up a hill is the commonest example of an inclined plane, and the gradient or slope of the road is often expressed thus: 1 in 50, *i.e.* in every 50 feet of length the road rises 1 foot in height, or, in other words, if the plane were 50 feet long, its height is 1 foot, and therefore the mechanical advantage is $\frac{50}{1}$, *i.e.* 50, whatever the actual length of the road might be.

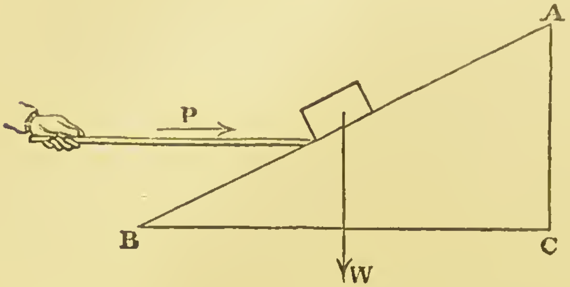

FIG. 240.

Instead of applying the force in a direction parallel to the length of the plane, it may be applied in a direction parallel to the base by pushing the resistance up the plane from behind (see fig. 240), or else by pushing the plane under the resistance (see fig. 241).

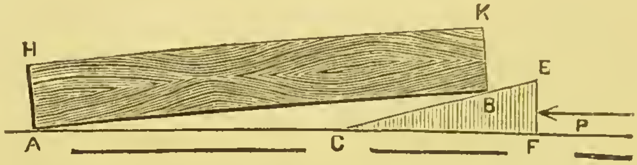

FIG. 241.

In this case we get the following relation :—

$$\text{Mechanical advantage} = \frac{\text{base of plane}}{\text{height of plane}}$$

An inclined plane applied in the manner shown in fig. 241 is called a *wedge*, though the latter usually consists of two inclined planes placed base to base (see fig. 242). A little consideration will enable the student to see that

$$\text{Mechanical advantage of wedge} = \frac{\text{length measured along middle base}}{\text{thickness at blunt end}}$$

since the resistance is moved through the thickness of the wedge and the power through its length.

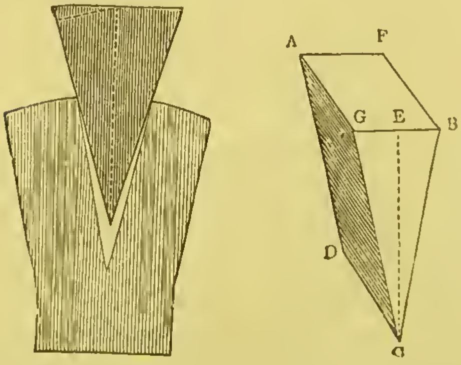

FIG. 242.

All instruments used for cutting or piercing purposes are wedges; *e.g.* knives, chisels, nails, axes, pins, needles, swords, etc.

Owing to the unevenness of the surfaces in everyday life, the above statements are not strictly true, since they apply to perfectly smooth surfaces, *i.e.* to surfaces between which there is no friction whatever, and which therefore do not exist in practice.

341. **The Screw.**—The screw is in reality a modification of the inclined plane, and consists of a central cylinder with a spiral ridge raised upon it. This ridge is called the

'thread,' *a d* and the distance between one thread and the next, measured parallel to the axis, A A is known as the 'pitch' of the screw.

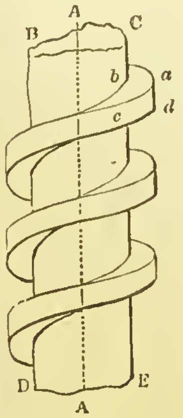

FIG. 243.

To use the screw we often have a hollow cylinder with a spiral groove cut on the inside of it, so that the screw exactly fits into it. This hollow cylinder is known as the *nut*.

When the screw has been turned round once, the nut, and therefore the resistance, has been moved through a distance equal to the pitch of the screw. The mechanical advantage of a screw is therefore got by dividing the circumference of screw by the distance between two successive threads.

In practice, however, the power is usually applied at the end of an arm or handle fixed to the screw or nut, and so, in one revolution of the screw, the power is moved through a distance equal to that of the circumference of the circle in which the handle moves. This obviously increases the mechanical advantage, for now it equals

$$\frac{\text{Circumference of circle through which end of handle moves}}{\text{Pitch of screw}}$$

By making the pitch of the screw very fine, and using a long arm to apply the power, an enormous mechanical advantage is obtained, though in use a great deal of this advantage is lost on account of friction.

Suppose the pitch of the screw is $\frac{1}{7}$-inch, and that the power is applied at the end of an arm 21 inches long, we get for our mechanical advantage—

$$\frac{\text{Circumference of circle of radius 21 inches}}{\text{Pitch of screw}}$$

$$= \frac{3\frac{1}{7} \times 2 \times 21}{\frac{1}{7}} = \frac{\frac{22}{\cancel{7}} \times \frac{2}{1} \times \frac{21}{1}}{\frac{1}{\cancel{7}}} = 924$$

that is, a force of 1 lb. applied at the end of the arm would produce a pressure of 924 lbs.

There are many useful applications of the screw, *e.g.* the screw-press and the instrument used for coining where the impression of a die is to be made upon the metal. In the common screw, the threads are thin and sharp, and make grooves for themselves as they penetrate the wood.

342. **Centre of Gravity.**—As already explained (par. 13), the weight of a stone or any other body is the force with which the earth tends to draw the body downwards.

If we consider the body to be made up of an immense number of small particles, we see that the attraction of the earth on each particle acts in a straight line perpendicular to the horizontal plane. These forces act towards the earth's centre and may therefore for all practical purposes be considered parallel.

The resultant of all these forces is equal to their sum, and acts at some definite point of the body. In other words, the whole weight of the body may be considered as collected at this point; and every mass, whatever be its shape, has such a point, to which the name of *centre of gravity* or *centre of mass* is given.

The centre of gravity of a body may therefore be defined as the point at which its weight acts, and about which, if supported, the body will rest in any position.

The centre of gravity of symmetrical bodies of uniform density is at their geometric centre; thus the C G of a uniform straight rod is at its middle point; that of a sphere at its centre; that of a square or rectangle at the intersection of its diagonals; that of a circular plate of uniform thickness at its centre; and so on.

The centre of gravity of any body may be found experimentally in the following way:—Suspend it from any point by means of a string and let it come to rest. Then the centre of gravity lies in the plumb-line drawn through the point of suspension, because the body is then acted upon by two equal and opposite forces, viz. gravity and the tension of the string, acting in the same straight line (par. 333, II.).

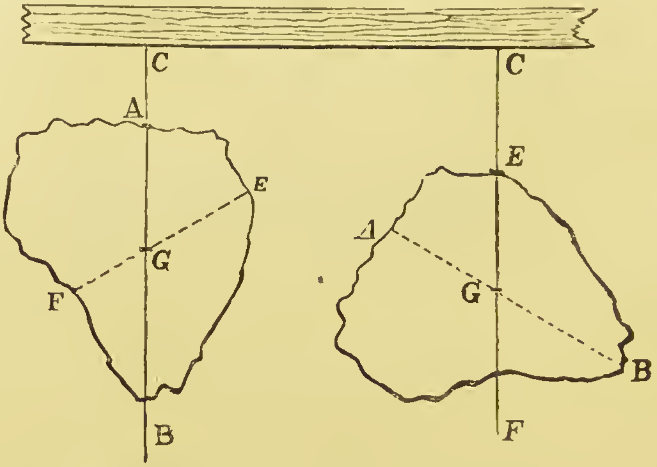

FIG. 244.—Showing how to find the Centre of Gravity experimentally.

Now suspend it from any other point, E, and again draw a vertical line through the point of suspension. As the centre of gravity is in both of these vertical lines, it must be at their point of intersection. We thus see that the weight of a body may be regarded as a force acting vertically downwards through the centre of gravity.

For a body to be at rest or in equilibrium, this force must be counterbalanced by an equal and opposite one. Now a body resting on a plane surface may be looked upon as under the action of two equal and opposite forces, viz. its own weight acting vertically downwards and the upward pressure of the surface it is resting upon, the latter being regarded as one force acting at a definite point. As long as the vertical from the centre of gravity falls *within* the base of support, the two equal and opposite forces can neutralize each other; but if the vertical from the centre of gravity falls *without* the base, there can be no equal and opposite force to counteract its weight, and the body falls over until it finds a position where

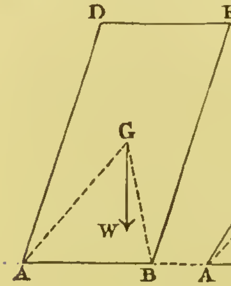

FIG. 245.

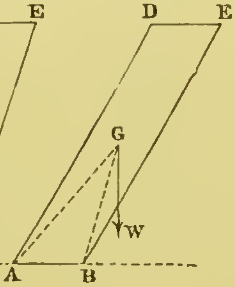

FIG. 246.

the two opposite forces balance each other (Figs. 245, 246). Hence, *a body placed on a horizontal plane will stand or fall according as the vertical through its centre of gravity falls within or without the base.* Thus the centre of gravity of any leaning structure, such as the tower of Pisa, must fall within the base, or it would fall.

Again, a body whose centre of gravity is low is not so easily displaced from its position of rest as one whose centre of gravity is high. Thus a cone resting on its base returns to its former position if disturbed but little; whilst a cone balanced on its apex falls with the slightest disturbance.

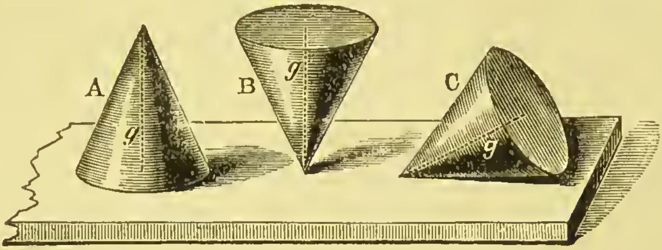

FIG. 247.

In the first case, where the centre of gravity is in the lowest position possible, the body is said to be in *stable equilibrium;* in the second case, where the centre of gravity is in the highest position possible, the body is said to be in *unstable equilibrium.* A body like a sphere, or a cone resting upon its side, which remains at rest equally in any position, is said to be in *neutral equilibrium.*

In the case of two bodies we could ascertain their centre of gravity, if we connected them with a rigid straight bar, and then found the point in the bar where they would balance. With two equal globes this point would be midway between the two. If one were heavier than another the centre of gravity would be nearer the heavier in the ratio of its greater weight, and were one much heavier than the other the centre of gravity would be within the larger. This is the case of the sun and the earth, the sun's mass being so much greater that the common centre of gravity of the sun and earth is very near the sun's centre.

The centre of gravity of a body need not of necessity be in the substance of the body; thus, in the case of a ring or hoop the centre of gravity is in the centre of the space within the ring or hoop.

(The student must not confuse *centre of gravity* and *specific gravity* (see par. 22). The specific gravity of a solid heavier than water is found by first weighing the body in air, and then in water. The loss of weight represents the weight of an equal bulk of water. Dividing the weight in air by the loss of weight in water therefore gives the specific gravity. In the case of liquids, the comparative weights can be obtained by finding the weight of a bottle full of water and the weight of the bottle full of the liquid given, subtracting the weight of the empty bottle in each case.)

Note to par. 199.—Recent investigations of Professor Rayleigh and Professor Ramsay have shown that what has been called *atmospheric nitrogen* is not wholly nitrogen, but that it contains besides nitrogen a small quantity of a gaseous substance new to science. This is called *argon.* Argon is an invisible gas somewhat lighter than nitrogen. It appears to be an element, and has but little chemical affinity. Hence the composition of dry air per 100 volumes may be put thus—

Nitrogen	78·00
Oxygen	20·96
Argon	1·00
Carbonic acid	·04
	100·00

Note to par. 218.—Dr. Wells's theory of the *formation* of dew explained in par. 218 is quite correct; but it has been proved that the vapour, which is condensed, rises mainly from the ground instead of falling from the air above. Mr. J. Aitken carried out a number of experiments showing that the greater part of true dew is formed from the vapour that rises from the heated ground and has been trapped by grass and other cold objects. One experiment which establishes this consists in removing at sunset a portion of the turf from the ground and weighing it in a metal pan. The turf is then left in the pan and replaced so as to be in good heat-communication with the ground. After the lapse of some time the turf is again weighed, when its weight is found to be sensibly diminished. By covering the turf thus removed and replaced with a thin sheet of metal, the loss of weight is largely prevented. Similar experiments proved that from bare soil and dry earth moisture always rises during the night. Moreover, the drops seen on grass and leaves are not dew at all, but moisture exuded from the living plant. These drops are only found at the extremities of leaf-veins, *i.e.* at the points where the veins of the leaves cut the outer edges. The true dew is distributed all over the blade as a moist film. The atmospheric conditions necessary to the copious formation of dew are set forth in the latter part of par. 218.

Lord Kelvin holds that the protective action exerted at night on vegetation by the aqueous vapour of the atmosphere is due, not so much to its power of absorbing the heat radiated from the earth's surface, as Tyndall teaches, as to its great heat-capacity. Blades of grass and the finer parts of plants would radiate away their heat below zero point, were it not that on still nights they are protected by the latent heat of the vapour deposited on them as dew. Their temperatures can never fall below the dew-point of the air touching them. On windy nights plants obtain heat to compensate for radiation from the air moving about among them; and on cloudy nights radiation is checked by the temperature of the clouds being near the dew-point of the lower air. 'Thus, either clouds, by their counter-radiation, or wind by mixing a comparatively thick stratum of air with that next the earth, keep the grass and delicate parts of other plants from sinking to the dew-point. When there is not enough of clouds and wind to afford this degree of protection, dew begins to form, and, by preventing the temperature of any leaf or flower from sinking below the dew-point, saves them all from destruction, unless, as when hoar-frost appears, the dew-point itself is below the freezing point.'

Note to par. 307.—It has already been stated that Kepler discovered his three laws by careful observation of the heavens, and that it was some years later before Newton explained why such law was true.

Kepler's First Law states 'The earth and the other planets revolve in ellipses, with the sun in one focus Newton explained this law by showing that the force acting on each planet varies inversely as the square of its distance from the sun.

Kepler's Second Law states: 'The radius vector of each planet moves over equal areas in equal times.' Newton concluded from this that the force causing a planet to describe its orbit is a central force always acting along the radius vector in the direction of the centre of the sun.

Kepler's Third Law states: 'The squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun.' This law was explained by Newton's conclusion that the force of the sun's gravitation on a planet varies directly as the planet's mass, and inversely as the square of its distance from the sun.

QUESTIONS IN PHYSIOGRAPHY.

Original and Selected

Answers should be illustrated by diagrams whenever possible. Keep the answers corresponding to the various parts of the same numbered question distinct.

QUESTIONS ON CHAPTER I.

1. What do you understand by the term *matter?* Enumerate the *general* properties of matter, and give examples of the great divisibility of matter.

2. What are the *general* and what are the *specific* properties of (*a*) a piece of sandstone and (*b*) a piece of ice?

3. If you take a jug of muddy water from the seashore, how could you remove the mud and other suspended matter; and how could you obtain the salt that is in solution?

4. Explain the term *inertia*, and give two illustrations of this property of matter.

5. What is weight? How would you show that air possesses weight?

QUESTIONS ON CHAPTER II.

1. Explain the terms *force*, *density*, and *mass*.

2. State and explain the law of gravitation as formulated by Newton.

3. Why does the weight of a body increase as we pass from the equator to the poles? What instrument would you need to show this increase?

4. Why does a stone weight fall no faster than a one-pound weight, and

yet the attraction of gravitation is fourteen times greater in the first case than in the second?

5. Why does a stone fall faster in the air than a feather? How could you show that in a vacuum both fall at the same rate?

6. Explain what is meant by specific gravity. Write down the specific gravities of iron, marble, quartz or rock-crystal, coal, ice, mercury, and distilled water at 39° F.

7. Describe how you could obtain pure water from sea-water.

8. Explain the term *cohesion*, and show how this force differs from that of *gravitation* and from *chemical affinity*.

9. What are the three states in which the various substances of nature occur? How may water be changed from one condition to another, and what change of volume does the liquid undergo when it passes into the condition of vapour?

10. What do you understand by a *saturated solution?* What often occurs as the water evaporates from such a solution?

11. Explain the terms *stress*, *momentum*, and *elasticity*. Why are gases said to be perfectly elastic?

12. What is the scientific meaning of the term *hardness?* Name the hardest of all substances, and write out Mohr's scale of hardness.

QUESTIONS ON CHAPTER III.

1. What is *work*, and how is it measured? What is *energy?*

2. Illustrate the meaning of the terms *kinetic* and *potential* as applied to energy?

3. 'Energy is indestructible'—'conservation of energy.' Explain these.

4. Why is the sun considered as the ultimate source of terrestrial energy?

QUESTIONS ON CHAPTER IV.

1. For what purpose is a thermometer used? Describe the mode in which a thermometer is graduated.

2. Why is mercury generally used in the construction of a thermometer?

3. Describe the black-bulb thermometer and its use.

4. 'Heat causes bodies to expand, and the withdrawal of heat causes bodies to contract.' Carefully explain how far water furnishes an exception to this statement.

5. What is meant by the boiling-point of water? Why is it not the same at the sea-level and at the summit of a mountain?

6. Explain the term 'specific heat,' and point out the importance of the great specific heat of water.

7. How does heat pass from the sun to the earth? What effect has the earth's atmosphere on the rays of heat passing through it?

QUESTIONS ON CHAPTER V.

1. Explain clearly the meaning of the terms *element* and *compound*. Why are *fire*, *earth*, *air*, and *water*, not spoken of as elements now?

2. How can you prepare pure oxygen gas? What binary compound is formed when charcoal burns in oxygen? Name three other oxides that can be formed in the same way.

3. Carefully write out—

   (*a*) A method of proving that water is a chemical compound by analysis.

   (*b*) A method of showing that water-vapour is formed when dry hydrogen burns.

   (*c*) The composition of water by weight and by volume.

4. What is the chemical composition of limestone and of lime? How can the latter be obtained from the former?

5. State carefully—

   (*a*) How carbon dioxide (or carbonic acid) can be readily prepared and collected.

   (*b*) What happens when this gas is passed for a short time into water containing lime in solution.

   (*c*) What happens when a large quantity of the gas is passed into lime-water.

6. When is a substance said to undergo a physical change, and when a chemical change? What kind of change is (*a*) turning water into steam? (*b*) the rusting of iron?

QUESTIONS ON CHAPTER VI.

1. Define the terms 'rock' and 'mineral,' giving three examples of each.

2. Give an account of the appearance and composition of the rock *granite.*

3. What are the two commonest rock-forming minerals? Of what chemical elements do these minerals consist?

4. What different forms of the mineral calcite do you know?

5. What three chemical elements exist in combination in the earth's crust in greatest amount? Which of these three is a metallic element?

6. Of what does coal chiefly consist? How does it differ from peat in chemical composition?

7. Point out the chief difference between stratified and unstratified rocks. By what other names is each of these classes known?

8. What are the characteristics of metamorphic rocks? Name some members of this class.

9. Mention some rocks that have a distinctly crystalline structure. What is the meaning of the term *crystal?*

10. Carefully state—

    (*a*) The chemical composition of coral.

    (*b*) The parts of the world where coral rocks abound.

    (*c*) Why coral is spoken of as an *organic* rock.

11. What are stalactites and stalagmites? Where are they likely to be met with? Explain distinctly how a stalactite is formed.

12. Describe carefully a piece of pumice-stone. How does it differ from a piece of basalt?

13. To what class of rocks do slate and gneiss belong? What minerals exist in gneiss, and how are they arranged?

14. How is soil formed, and of what does it chiefly consist?

15. Rock strata, *i.e.* layers of stratified rocks, have frequently lost their horizontal arrangement. Account for this.

16. Tell what you know of the origin and chemical composition of (*a*) grains of sand, (*b*) sinter, (*c*) kaolin, (*d*) shale, (*e*) obsidian.

QUESTIONS ON CHAPTER VII.

1. How does the temperature of the earth's crust vary as we pass into it? What is meant by 'the stratum of invariable temperature'?

2. Give an account of the chief events that occur during a volcanic eruption.

3. Carefully enumerate and describe the chief products of a volcanic eruption.

4. Tell what you know about a *lava stream.* What are *acid* lavas and *basic* lavas?

5. Enumerate the different varieties of volcanic cones, and illustrate by means of a diagram the structure of a composite cone.

6. Point out the mistakes in the following: 'A volcano is a burning mountain that ejects smoke and ashes.'

7. Write a short description of each of the following: *a volcanic bomb*, *scoriæ*, *lapilli*, a *lateral crater*, a *fumarole.*

8. Trace out the line of volcanoes that borders both sides of the Pacific Ocean.

9. In what parts of the world are earthquakes most frequent? How is the point of origin of an earthquake shock ascertained?

10. What proofs have we that variations of land-level occur in different parts of the world? Carefully describe a *raised beach.*

11. On what shores is the land now sinking? What proofs of land subsidence may be pointed to?

QUESTIONS ON CHAPTER VIII.

1. State as accurately as you can—
    (*a*) The two chief solids in solution in sea-water, and the percentage amount of these solids.
    (*b*) The way in which you could obtain these solids from a quantity of sea-water.
    (*c*) The sea that contains the largest percentage of solid matter in solution.
    (*d*) The average density or specific gravity of sea-water.

2. Give an account of the mode in which a deep-sea sounding is made, and how a specimen of the ocean floor is brought up.

3. Describe, with the aid of a sketch map, the floor of the Atlantic Ocean.

4. What do you know about the temperature of the ocean, (*a*) at the surface, (*b*) at great depths?

5. Explain how the sea acts in destroying the coast in various districts.

6. Enumerate the different varieties of deposits that are found on the ocean floor, and say at what depth each kind is met with.

7. What becomes of—
   (*a*) The calcium carbonate dissolved in sea-water?
   (*b*) The slight quantities of silica dissolved in sea-water?
   (*c*) The angular boulders broken off a cliff by the action of the waves?
   (*d*) The calcareous shells of Foraminifera that fall into the deepest parts of the ocean?

8. Compare the microscopic appearance of chalk and Globigerina ooze.

9. What is the average percentage of solid matter dissolved in sea-water? Why are some inland seas salter than the open ocean, while some are less salt?

10. What different varieties of ooze have been found on the ocean floor?

11. What is known about the manganese nodules and cosmic spherules dredged from deep parts of the sea?

QUESTIONS ON CHAPTER IX.

1. What are an *ice-foot*, an *ice-field*, and an *ice-floe?*

2. How do Antarctic icebergs differ from Arctic icebergs?

3. Tell what you know about the origin of icebergs? What ultimately becomes of them and of the material they transport?

QUESTIONS ON CHAPTER X.

1. What are the two chief gases that enter into the composition of the atmosphere, and in what proportion by volume do these exist? How could you prove that the air also contains a small quantity of carbon dioxide? Why do we say that the gases of the atmosphere are only mechanically mixed and not chemically combined?

2. Explain the mode in which the quantity of water-vapour in the atmosphere is estimated.

3. Explain the construction of a barometer. What does the barometer really measure?

4. What liquid is generally used for a barometer tube, and why? What is the advantage of using glycerine?

5. How can a barometer be used to measure the height of a mountain, or the height to which a balloon ascends? What would be the effect of taking a barometer down a deep mine?

6. Why does the height of the mercury in a barometer tube vary? Why does a high barometer usually indicate that the air is dry?

7. In what way is the air heated by the sun's rays? Clearly explain why the air becomes colder as we ascend.

8. What are *isobars* and *isotherms?* What data are required in order to draw these lines for Europe?

9. Regarding land and sea breezes, clearly set forth—
   (*a*) Why they blow in certain parts of the world.
   (*b*) At what time of the day each breeze blows.
   (*c*) Why these are but little noticed in Great Britain.

10. Trace the course of the isotherm of 60° F., and explain why it does not coincide with a parallel of latitude.

QUESTIONS ON CHAPTER XI.

1. What becomes of the rain that falls on the rocks or on the pavement during a warm summer day?

2. Of what does dew consist? From what sources is it derived? What atmospheric conditions are favourable to its deposition?

3. Of what does a fog consist? What part do dust-particles play in its production? Where are fogs most frequent?

4. Explain the construction and use of the rain-gauge.

5. Write down—
   (*a*) The mean annual rainfall of the west side of Britain.
   (*b*) The mean annual rainfall of the east side of Britain.
   (*c*) The main cause of the difference between those two.
   (*d*) The place in England with the greatest annual rainfall, and the place with the least.

6. In what parts of the world is there no rainfall? Account for this extreme dryness in three cases.

7. What portions of the globe have *rainy seasons*, and when do these rainy seasons occur?

8. Why has the eastern side of the British Isles less rainfall than the western side? What is the mean annual rainfall of the town where you live, and how is it found?

9. Draw some forms of snow-crystals. In what parts of the world is snow never seen at the sea-level?

10. Define *snow-line*, and give the height of the snow-line at the equator, in Central Europe, and in Scotland. What circumstances influence the height of the snow-line besides latitude?

11. Account for (*a*) the great rainfall on the Khasia Hills in Assam; (*b*) the arid nature of the desert of Gobi; (*c*) the inhospitable climate of Labrador; (*d*) the genial warmth of North Italy.

12. Briefly describe the formation and structure of (*a*) a barrier reef; (*b*) pack ice; (*c*) a terminal moraine.

QUESTIONS ON CHAPTER XII.

1. Explain the terms *denudation*, *erosion*, and *débris*, and name the chief agents of denudation.

2. Give some account of the action of the atmosphere, and the rain upon rocks.

3. Point out the action of rivers on the surface of a country. What is a *river-terrace?*

4. What rivers form deltas? Of what does a delta consist? How does it happen that the bed of a river in a delta may be higher than the general level of the land around?

5. What are *surface springs*, and how are they formed? Mention other varieties of springs, and describe one of them.

6. What causes a glacier to move? How has the motion been proved? Compare the rate of motion in Alpine and Arctic glaciers?

7. In what way does a glacier act as an agent in transporting rocks? Why are the waters that issue from a glacier usually very turbid?

8. By what indications do we infer the presence of glaciers in districts where they are no longer found?

9. Briefly describe each of the following: pot-hole, gorge, cañon, alluvium, sand-bank, glacier table, moulin, *roche moutonnée*, *dyke*.

10. What are *contour lines?* And what can be learnt from their inspection?

11. Account for the following statements:—
    (*a*) All the rivers run into the sea, yet the sea is not full.
    (*b*) The sea owes much of its salt to fresh-water streams.
    (*c*) There would be no snow if it were not for the heat of the sun.

QUESTIONS ON CHAPTER XIII.

1. What is meant by *weather?* Describe some form of weather chart, and explain how it is drawn up.

2. Give examples to show how height above the sea-level affects the climate of certain towns.

3. What are *insular* and *continental* climates? Illustrate the meaning of the terms by examples.

4. Compare the summer and winter climates of Central Russia, London, and Manitoba (all about the same latitude), and account for the differences.

QUESTIONS ON CHAPTER XIV.

1. Into what three great groups are the stratified rocks divided, and what are the formations that belong to each group?

2. Explain the meaning of the term *fossil*, and mention the names of any that you can recognize with the geological formation to which they belong.

3. What has been the general order of progress in plant and animal life on the earth?

4. Name some animal forms that have become extinct.

5. On what grounds do we conclude that the climate of Britain has varied greatly during geological epochs?

QUESTIONS ON CHAPTER XV.

1. What is the peculiar property of a magnet? Why do we regard the earth as a great magnet? Where are the magnetic poles of the earth?

2. Explain what is meant by the *declination* and *dip* of a magnetic needle. How does the declination vary from year to year?

3. What is meant by electrical induction?

4. Describe the different forms of lightning, noting especially the form of forked lightning as shown by photography.

5. How is it that the lightning flash usually precedes the peal of thunder? Where are thunderstorms most frequent?

6. Tell about the aurora borealis what you know concerning (*a*) its appearance; (*b*) the districts where it is seen; (*c*) its connection with the magnetism of the earth.

QUESTIONS ON CHAPTERS XVI. AND XVII.

NOTE.—*Illustrate your answers by diagrams when possible.*

1. Explain a system of measuring angles.
2. Illustrate the use of angular measurement in astronomy.
3. Explain the means of measuring time by a clock.
4. What is a sun-dial? What kind of time does it indicate?
5. Why do we say that the earth is a globe?
6. How do you account for the slight bulging at the equator? By how much does the equatorial radius exceed the polar radius?
7. Explain the terms *latitude* and *longitude*. What places on the earth's surface have their noon at the same time?

8. When it is noon at London, what is the time (1) at New York, long. 73° 55′ W., (2) at Constantinople, long. 29° E.?

Ans. 7 h. 4 m. A.M. at New York; 1 h. 56 m. P.M. at Constantinople.

9. Define the following terms: axis, equator, horizon, zenith, meridian.

10. How will you find the pole star at night in the northern hemisphere? What are *circumpolar* stars? Where will a person situated at the equator see the pole star?

11. Give three proofs that the earth rotates on an axis.

12. Describe the sun's apparent eastward motion among the stars, and show by a diagram that a real motion of the earth in the opposite direction will explain this phenomenon.

13. What is the evidence in favour of the annual revolution of the earth? When is the earth's velocity in its orbit greatest?

14. What is the shape and size of the earth's orbit? Explain the terms *perihelion* and *aphelion*.

15. How are the planes of the earth's orbit, of the ecliptic and of the equator related to each other?

16. Explain the daily appearances of the heavens to an observer (1) in a high northern latitude, (2) in mean latitude, (3) at the equator.

17. What are the causes which regulate the amount of heat received from the sun at any one place on a certain day?

18. Give an account of the different kinds of *day* spoken of in astronomy. Why does the true solar day vary in length?

19. How does the shadow of a vertical stick indicate the midday altitude of the sun? When is this shadow shortest, and with what line does it then coincide?

20. What are the causes of the seasons? What effect would be produced on the seasons were the earth's axis to be perpendicular to the plane of its orbit or to lie in it? (See p. 245.)

21. 'Within the Arctic circle at the summer solstice we can see the midnight sun due north, but at the winter solstice we do not see the sun even at noon.' Explain this, illustrating by means of diagrams.

22. When are the days and nights equal in all parts of the world, and why are they not always equal in all parts? Where are they always equal?

23. Give the length of the longest day at the *pole*, in latitude 75°, 50°, 30°, and at the *equator*.

24. Draw a diagram to show the apparent altitude of the sun as seen from London at midsummer and midwinter. (Figs. 149 and 150 may be used, a point between the Arctic circle and the Tropic of Cancer being taken for London. A line from the centre of the earth through the position of the observer will give the direction of the zenith.)

25. Explain fully why it is hotter in summer than in winter.

26. What yearly changes are there in the appearances of the stars, and how are they accounted for?

27. How often is the sun vertically overhead for a place within the tropics, and on what dates for a place on the equator?

28. What decides the length of the year exactly, and what decides how many whole days there are in it?

29. What are sidereal, tropical and civil years?

30. Give a short summary of the general effects of the earth's rotation and revolution.

31. What is the experiment of a falling body which is adduced in favour of the earth's rotation?

32. State the argument in favour of the annual motion of the earth derived from the law of gravitation.

33. Why do the stars rise a little earlier on each succeeding evening? What produces the difference between a solar and a sidereal day?

34. 'The sun keeps describing a larger and larger arc in the sky as the season advances.' Account for this.

35. Explain the following:—The constant parallelism of the earth's axis, solstice; torrid zone; mean solar time; ecliptic; azimuth; Foucault's pendulum experiment.

36. Carefully describe the gradual change in the length of day and night in the Temperate Zones.

37. What difference would be seen in (1) the daily path of the sun, (2) the daily path of the stars, by an observer in the south of England, and by an observer in the north of Scotland?

38. How would you recognise the eastward motion of the sun in the ecliptic?

39. Describe the essential parts of a telescope, and explain what each part really does.

40. Describe a form of reflecting telescope. Give a diagram of it.

41. What would be the effect on the seasons (*a*) if the earth's axis were inclined at an angle of 45° to the ecliptic; (*b*) if the earth's axis were perpendicular to the ecliptic?

42. Describe the transit circle and its uses.

43. How does refraction affect the position of a star?

44. What is *parallax?*

45. Explain what is meant by the aberration of light. How does it affect the position of a star?

46. By means of a gnomon, or vertical pillar, how could you find (*a*) the north and south line, (*b*) the date of the solstices?

47. Explain the construction and use of a *vernier.*

48. Describe some form of *micrometer.*

49. Show why a sidereal day is shorter than a solar day. What is a *mean* solar day? When is the true solar day longest?

50. How can a transit instrument be used to detect the error of a sidereal clock?

51. Explain the terms *declination* and *right ascension.* What causes the variation in the sun's declination during the year, and what is the result of this variation?

52. How may the shape of the earth's orbit be determined?

53. Show by a diagram the variation in the declination and amplitude of the sun (*a*) at the equator, (*b*) in latitude 45° N.

54. Where and when can the sun be seen at midnight? In what part of the sky is it then visible?

55. What is meant by (*a*) the aberration orbit of a star? (*b*) the annual parallax of a star? What do these phenomena prove?

56. Why do the seasons differ in length?

57. What is 'Greenwich mean time,' and how is it found?

58. Tell briefly how you would find (*a*) the position of the pole star; (*b*) the position of the celestial equator; (*c*) the time of the earth's rotation.

59. Briefly explain (*a*) why the sun never reaches the zenith in any part of the British Isles; (*b*) why it is warmest in the British Isles when the earth is farthest from the sun; (*c*) why the hottest part of the year in the British Isles is usually about the end of July.

60. Write down, (*a*) how many times the earth rotates in a year; (*b*) the altitude and zenith distance of the pole star at London; (*c*) the declination and right ascension of the sun on September 23.

61. What are the three kinds of year, and why do they differ in length?

62. Draw a diagram for latitude 45° N., and show the diurnal paths of stars with declination 0°, 30° N., 80° N., 20° S., 75° S.

63. Briefly describe a transit telescope and its uses.

64. What time is kept by a sidereal clock, and how is this clock regulated?

65. Define equation of time. At what parts of the year is there the greatest difference between true solar time and mean solar time, and why?

66. According to the almanacs the lengths of forenoon and afternoon often differ: how do you explain this?

67. How can a celestial globe be used to illustrate the diurnal paths of the stars, and of the sun at various latitudes?

68. Briefly explain (*a*) why the amplitude of the rising and setting sun varies; (*b*) why a star's amplitude is the same day after day; (*c*) why a star rises a little earlier on successive nights.

69. How do you account for (*a*) the changes in the apparent diameter of the sun during the year; (*b*) the different heating effects of the sun's rays at the summer and winter solstices?

70. Explain the terms:—ecliptic, plane of the ecliptic, obliquity of the ecliptic, first point of Aries, celestial latitude, celestial longitude.

71. When are the days shortest, and why?

72. How has the shape of the earth been determined? What is the length of a degree of latitude near the equator and near the poles?

73. Explain what is meant by the equation of time? Point out its two components, and tell the objects that the equation serves.

74. How do you account for the frequent inequality of length between forenoon and afternoon as put down in the almanacs?

75. How can a celestial globe be used: (*a*) To show the diurnal paths of the stars at various latitudes? (*b*) To explain the varying altitude of the sun? (*c*) To show why the sun in Britain rises north of east at one part of the year and south of east at another part?

76. How do you know that light is propagated in a rectilinear direction, *i.e.* in straight lines?

77. How is light reflected from a plane surface? Write out the law, and draw a figure. How may it be reflected from a curved surface?

78. What is meant by the refraction of light? and state some of its effects. How is the image formed in a refracting telescope?

79. Give an account of the action of a flint glass prism on a beam of white light. How do light rays differ from radiant heat?

80. In what different ways can the prismatic colours be recombined?

81. Give proofs of the composite nature of white light, and state how you could render the spectrum of sunlight visible. Name the prismatic colours of the spectrum.

82. What is the mean distance of the sun from the earth? When is the distance greatest, and when least? Compare the dimensions of the sun and the earth.

83. Write out Kepler's Laws, and state briefly how Newton explained them.

84. Write down the distance, size, density, and physical condition of the moon. How is its distance found?

85. Give an account of the various phases passed through by the moon

in a lunar month. What is a lunar month, and why is it longer than a sidereal month?

86. Under what conditions do lunar eclipses occur? Illustrate by a diagram.

87. Under what conditions may a total eclipse of the sun occur? Why is the field of totality so limited? Where is the eclipse only partial?

88. Explain the circumstances that may give rise to an annular eclipse of the sun. Illustrate by a diagram.

89. Briefly explain (*a*) why eclipses do not occur every month, (*b*) why there cannot be an annular eclipse of the moon, (*c*) why solar eclipses are so seldom seen at any given place.

90. What do you understand by the terms: the moon's nodes, conjunction, opposition, quadrature, last quarter, partial eclipse?

91. Describe the effects of atmospheric refraction on the position of a heavenly body.

92. Explain the construction of a horizontal sundial. Why is one constructed for Paris of no use in any part of Britain?

QUESTIONS ON THE APPENDIX.

1. Distinguish between mass and weight. What is momentum, and how is it measured?

2. State the principle of the parallelogram of forces, and illustrate it by an example drawn to scale.

3. How can force be represented, and how can a single force be resolved into component forces?

4. Explain the principle of the lever, and state how you can calculate its mechanical advantage in any case.

5. Sketch a fixed pulley and a single movable pulley, and then point out the mechanical advantage (if any) in each case.

6. Explain the principle of the inclined plane. An inclined plane rises three feet six inches for every seven feet of length. If W = 100 lbs., find P when it acts parallel to the length of the plane.

7. Show how rectilinear motion can be converted into circular motion.

8. A stone is being whirled by a string, and the string suddenly breaks. In what direction will the stone fly off, and why?

9. Explain clearly what you understand by the terms *velocity*, *centripetal force*, and *centrifugal force*.

10. Define "centre of gravity' and 'specific gravity.' Explain how to find each in the case of a piece of marble slab.

11. Where is the centre of gravity of a globe, of two equal spheres ten yards apart, of the earth and the moon? When will a leaning tower fall over?

12. What new gaseous constituent of the atmosphere has been recently found? Give the percentage of gases forming dry air.

13. When a candle burns in the air, is the matter of the candle destroyed? (See pars. 72 and 74.) What constituent of the air is used in combustion?

14. State Kepler's Laws and Newton's deduction from each.

SCIENCE AND ART DEPARTMENT.

SYLLABUS.

SUBJECT XXIII.—PHYSIOGRAPHY.

First Stage, or Elementary Course.

Matter.—Forms of matter. Indestructibility of matter. Mass, volume, density, specific gravity, and weight. Centre of gravity.

Force, Motion, and Inertia.—The parallelogram of forces. Composition and resolution of forces. Conversion of rectilinear into circular motion. (See Appendix.)

The Mechanical Powers.—Principles of the lever, the pulley, the inclined plane, and the screw. (See Appendix.)

Energy.—Heat, radiation, electricity, and chemical action as forms of energy. Mechanical work.

Heat and Temperature.—Discrimination between heat and temperature. Effects of heat. The measurement of temperature by thermometers. Change of state caused by heat, as in ice, water, and steam.

Radiation.—Rectilinear propagation of radiation. Reflection and refraction of radiation. The analysis of light by a prism, and its recomposition. The colour disc. The visible spectrum. (See Chapter XVII.)

Chemical Composition of Matter.—Mixtures and compounds. Water, its composition proved by analysis and synthesis, its physical properties. Elementary properties of oxygen, nitrogen, hydrogen, carbon, iron, and mercury; and of water, carbon-dioxide, lime, silica, and the alkalies, common salt, iron oxide, and mercuric oxide.

The Earth, the Sun, and the Moon.—Form, density, and dimensions of the earth. Rotation of the earth on its axis. Latitude and longitude. Density and dimensions of the sun. Distance of the earth from the sun. Inclination of the earth's axis. The general features of the earth's orbit. Kepler's laws, and Newton's explanation of them. Cause of variation in length of day and night. The four seasons. Distance and dimensions of the moon; lunar and solar eclipses.

Measurement of Space, Mass, and Time.—Units of space and mass are empyrical. Measurement of angles. Subdivision of the day into hours, minutes, and seconds. The sun-dial. Greenwich and local times.

The Atmosphere.—Weight of the air, pressure on the earth's surface, height of the atmosphere. Boyle's law. The principle of the mercurial barometer. Pressure of the atmosphere at different altitudes. Composition of the atmosphere and the diffusion of gases; animal and vegetable life in relation to the atmosphere. Isobars. The manner in which the atmosphere is warmed and its temperature at different elevations. Isotherms. Fog, mist, clouds, rain, snow, hail, dew, and hoar-frost. Winds and their causes. Circulation of the atmosphere. Land and sea breezes; monsoons and hurricanes; trade-winds and their causes. Rainfall; method of measurement.

The Sea and Circulation of Water on the Land.—Composition of sea water. Its specific gravity and freezing point. Proportion of land to water. Division into oceans and seas. Sea level. Depths of oceans. Circulation of water. Currents in the oceans. Effect of temperature on seas. Springs and rivers.

Rivers and Glaciers.—Tidal rivers and deltas. Glaciers and formation of moraines. Icebergs.

The Earth's Solid Crust and the Changes which take Place in it.—General classification of rocks into aqueous, igneous, and metamorphic. Their characteristics and common examples of each. Their chemical components and modes of occurrence. Earthquakes, volcanic phenomena, action of the atmosphere and water. Constructive and destructive action of organisms such as result in the formation of limestone, coral-reefs, and coal. Specific gravity and hardness of rocks. Density of the earth as a whole.

Terrestrial Magnetism.—Properties of the lodestone and artificial magnets. The earth a magnet. Primary laws of magnetic attraction and repulsion. Dip. The earth's magnetic poles.

Much of the apparatus used in teaching Physics, Chemistry, and Geology will be available for Physiographic teaching. The following pieces of apparatus are recommended for teachers of Physiography:—Maximum, minimum, and black-bulb thermometers. Barometer. *Barometer tube with mercury, a cup and a wooden clip-stand for setting up a barometer before the class.* Rain gauge, simple. Ordnance survey map of district, showing contour lines. Terrestrial globe, not less than 12 in. diameter. Geological map of the British Isles. Apparatus for simple experiments in magnetism, electricity, and chemistry. The articles required are, *in addition to a mouth blow-pipe*, those marked (*a*) and (*b*) under the heads of Subjects IX. and XIV. *Collection of* 12 *common rock-forming minerals. Collection of* 20 *common rocks. Collection of* 12 *microscopic slides illustrating Physiography. Collection of* 12 *slides, typical rocks. A cheap microscope. Diagrams illustrating terrestrial phenomena and astronomical objects.*

N.B.—A cheap telescope and a spectroscope also are very desirable.

EXAMINATION PAPERS.

1889. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions.*
The value attached to each question is the same.

1. Name *five*, *very common*, rock-forming minerals, and state what chemical elements are present in each of them.

2. What differences occur in the apparent paths of the stars across the sky, as we proceed from the equator to the pole? What is the cause of this difference?

3. Explain the chief reasons why mercury is the liquid usually employed in the construction of—
   (*a*) Barometers.
   (*b*) Thermometers.

4. Explain by diagrams why the sun appears high in the sky at noon in summer and low at noon in winter.

5. How can the weight of air be determined? In what way is the pressure exercised by the atmosphere on the earth's surface, in consequence of its weight, stated? How is it that we are able to move about under the weight of the atmosphere?

6. What is sidereal and what is mean time?

7. State the grounds on which it is inferred that volcanic eruptions take place through fissures in the earth's crust.

8. Describe shortly the construction of an achromatic astronomical telescope.

1890. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions.*
The value attached to each question is the same.

1. (*a*) Name the two elements which are present in the greatest abundance in the earth's crust. (*b*) State what you know about the nature of these elements. (*c*) In what condition do these elements exist in the earth's crust?

2. In the case of a shot fired at a target, state (*a*) why the velocity of the shot changes; and (*b*) why the target is made hot where the shot strikes it.

3. (*a*) What becomes of the water of puddles when they "dry up"? (*b*) What conditions of the air are most favourable to the process? (*c*) State the reasons why these conditions are favourable.

4. Give experiments showing how any two binary compounds can be formed.

5. What is meant by the statement that the mean annual rainfall of a place is 27 inches? State what you know concerning the mean annual rainfall of different parts of the British Islands.

6. How has it been shown that the plane of the earth's equator is inclined to the plane of the ecliptic? What is the amount of that inclination?

7. How has it been found out that the deeper parts of the earth's crust are hotter than those near the surface?

8. What is the "equation of time," and what use is made of it?

1890. TRAINING COLLEGE EXAMINATION.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* SIX *questions.*
The value attached to each question is the same.

1. Account for the different heights of the sun at noon throughout the year.

2. Give proofs of the rotation and revolution of the earth.

3. What is mean solar time, and how is it determined?

4. What are momentum and kinetic energy? Show how they are measured.

5. Explain the changes which a cubic inch of ice would undergo when its temperature was gradually raised from −5° C. to 105° C.

6. What minerals are present in granite? In what respect does a granitic rock differ from a lava? What kind of lava has the same chemical composition as granite?

7. What do you know concerning the transportation of rock-materials by floating ice?

8. How is the rainfall of a place determined for each month of the year?

N.B.—In the future examinations in the elementary and advanced stages, questions will be given in two groups; one of them containing questions which relate principally to physical geography, and the other will contain questions in the other part of the syllabus. Students will be required to answer questions in both groups.

1891. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions, three of which must be taken from one Series, and two from the other.*
The value attached to each question is the same.

SERIES I.

1. What chemical element is present both in air and water? State the chief properties of this elementary substance. What proportion of this element is contained in air and water respectively? In what condition does the element exist in air and water respectively?

2. State the principle on which the action of a mercurial barometer depends. Why is a water barometer longer than a mercurial barometer? What occupies the space above the mercurial column in the latter instrument? If a hole were to be bored through the glass above the column of mercury, what would happen?

3. What is the source of the water that falls as rain? What becomes of it when it reaches the ground? How do we indicate the quantity of rain which falls upon a given place during a year?

4. What is meant by a "raised beach"? What do we learn from its existence? Name any place where raised beaches are found.

SERIES II.

5. How are the light and heat produced—
   (*a*) When a match is struck?
   (*b*) When a candle burns?
   (*c*) In a flash of lightning?
6. How would you set out a north-and-south line—
   (*a*) By a mariner's compass?
   (*b*) By the sun?
   (*c*) By a star?

7. What difference is observed in the place of the rising and setting of the sun (1) at different times of the year at any place in the British Isles; (2) at the summer solstice in different parts of the northern hemisphere?

8. State one experimental proof of the earth's rotation.

1891. TRAINING COLLEGE EXAMINATION.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions, three of which must be taken from one Series, and two from the other.*

The value attached to each question is the same.

SERIES I.

1. Describe the uses of the transit circle.

2. State some of the *results* of the *precession* of the equinoxes.

3. Given a circle reading to 20 minutes of arc, how do you construct a vernier reading to 10 *seconds of arc?*

4. Describe one of the methods employed for determining the *mean density* of the earth.

SERIES II.

5. State as shortly as possible what you know on the following points:—
   (*a*) The two most important substances found in the atmosphere in addition to oxygen and nitrogen.
   (*b*) The chemical composition of those two substances.
   (*c*) The processes by which each of these substances is introduced into the atmosphere.
   (*d*) The processes by which each of these substances is removed from the atmosphere.

6. Explain—
   (*a*) The differences between a snowflake and a hailstone.
   (*b*) The causes to which these differences are due.

7. Describe (*a*) the characters, (*b*) the mode of formation, of scoriæ, pumice, and volcanic dust.

8. State what is meant by the following phrases:—
   (*a*) The highest summer temperature of a place.
   (*b*) The lowest winter temperature of a place.
   (*c*) The mean annual temperature of a place.

And explain—
   (*d*) How each of the above can be determined.

1892. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions, three of which must be taken from one Series, and two from the other.*

The value attached to each question is the same.

SERIES I.

1. (*a*) What is an oxide?
   (*b*) Name two oxides which are always present in the atmosphere, and give their composition.
   (*c*) What is the most abundant oxide in the crust of the globe?
   (*d*) State what you know concerning the composition and mode of occurrence of this oxide.
2. (*a*) Why is the tube of a thermometer made with a narrow bore, while the bulb is large?
   (*b*) Why is the top of a thermometer tube sealed up?
   (*c*) Why is mercury the best liquid to use in a thermometer under ordinary circumstances?
   (*d*) Under what circumstances is alcohol used instead of mercury?
3. State the origin of the following appearances about an active volcano:—
   (*a*) The clouds which collect above it.
   (*b*) The glow seen above it at night.
   (*c*) The flashes of lightning playing about the cloud.
   (*d*) The sounds which are heard.
4. If you ascended to the height of 3½ miles in a balloon, carrying a barometer and a thermometer, state—
   (*a*) The indication which would be given by the barometer.
   (*b*) Your explanation of this.
   (*c*) The indication given by the thermometer.
   (*d*) Your explanation of this.

SERIES II.

5. Define force, energy, momentum, stress.

6. What are the facts which prove that the earth revolves round the sun, and not the sun round the earth?

7. How has the shape of the earth's orbit been determined?

8. What is sidereal and what is mean time?

1893. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions, three of which must be taken from one Series, and two from the other.*

The value attached to each question is the same.

SERIES I.

1. State the composition of water—
   (*a*) By weight.
   (*b*) By volume.

And describe how the composition of water may be demonstrated—
   (*c*) By separating its elements.
   (*d*) By uniting its elements.

2. (*a*) Why does the mercury stand higher in the tube than in the cup of a barometer?
   (*b*) What is the average height of the mercury in a barometer tube at the sea-level?
   (*c*) Why does the height vary from time to time?
   (*d*) Why is the barometer regarded as a "weather-glass"?
3. Point out the errors in the following statements:—
   (*a*) "Earthquakes have raised to heaven the ocean-bed."
   (*b*) "Volcanoes are burning mountains that vomit fire and smoke."
   (*c*) "Coral insects are industrious creatures that cleverly build up islands."
   (*d*) "Coal is a mass of leaves pressed together in the earth."
4. State what you know of the nature and direction of—
   (*a*) Trade winds.
   (*b*) Monsoons.
   (*c*) Anti-cyclones.
   (*d*) Sea breezes.

SERIES II.

5. Define the terms "energy" and "cohesion," and give examples of the action of chemical, magnetical, and gravitational attraction.

6. How is angular space measured? Describe the construction and applications of a vernier.

7. Why are the days longer in summer than in winter? Explain the difference noted in those seasons—
   (*a*) In the sun's declination.
   (*b*) In the place of sunrise and sunset.

8. Give an account of the apparent movements of the stars depending upon—
   (*a*) The earth's rotation on its axis.
   (*b*) The earth's revolution round the sun.

1894. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* FIVE *questions, three of which must be taken from one Series, and two from the other.*

The value attached to each question is the same.

SERIES I.

1. (*a*) Name the chemical elements which are present in carbonate of lime (calcic carbonate).
   (*b*) State the nature of each of these elements.
   (*c*) How can carbonate of lime be broken up into two oxides? What are these oxides called?
   (*d*) Name three common rocks which are composed of carbonate of lime.
2. (*a*) How can it be proved that the air has weight?
   (*b*) In what proportions and in what condition are oxygen and nitrogen present in air?
   (*c*) Describe experiments by which oxygen can be taken out of air and collected in a separate vessel.
   (*d*) Describe an experiment by which nitrogen may be separated from the oxygen in the air.
3. Describe—
   (*a*) Cloud.
   (*b*) Rain.
   (*c*) Hail.
   (*d*) Snow.

And state the mode of formation of each.

4. State the composition of the materials ejected from—
   (*a*) Fumaroles.
   (*b*) Geysers.
   (*c*) Mud-volcanoes.
   (*d*) Ordinary volcanoes.

SERIES II.

5. How is the position of a heavenly body defined—
   (*a*) In relation to the plane of the equator?
   (*b*) In relation to the plane of the ecliptic?
6. State what you know of the equation of time—
   (*a*) In relation to its amount at different times of the year.
   (*b*) In relation to its use in determining the moment of mean noon.
7. State the apparent daily movements at London of stars situated near north declination 90°, 51°, 39°, on the equator, and near south declination 20° and 38°.
8. How has the shape of the earth's orbit been determined?

1895. MAY.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to ATTEMPT *only* SIX *questions, three of which must be taken from each Series.*

The value attached to each question is the same.

SERIES I.

1. (*a*) What is the most abundant oxide in the earth's crust, and of what elements is it composed?
   (*b*) State what you know about the properties of this oxide.
   (*c*) Name the crystalline form of this oxide.
   (*d*) Name three rocks in which this oxide is found in its crystalline form.
2. (*a*) State the average height of the mercury in a barometer at the sea level, and at the top of a mountain 3½ miles high.
   (*b*) What is the cause of the difference in height of the mercury column?
   (*c*) What do you know concerning the height to which the atmosphere extends?
   (*d*) What do you know concerning the condition of the upper layers of the atmosphere?
3. (*a*) Draw and describe a rain-gauge.
   (*b*) Why is the water of a rain-gauge transferred to another vessel for measuring?
   (*c*) What is meant by the statement that "the mean annual rainfall in the Thames Valley is 27 inches"?
   (*d*) How has this been determined?
4. State the causes of—
   (*a*) The violent explosions that occur during a volcanic eruption.
   (*b*) The darkness that often exists during the day when an eruption is taking place.
   (*c*) The bright glow that is seen above a volcano at night.
   (*d*) The lightnings that accompany volcanic outbursts.

SERIES II.

5. What changes of volume take place when water freezes? State some effects produced.

6. Describe the Mariner's Compass and its chief uses.

7. State a proof that the earth moves round the sun.

8. Why are the days longer in summer than in winter? Give a diagram explaining the sun's altitude at noon at London on the longest and shortest day.

INDEX.

The numbers refer to paragraphs, and not to pages.

Aberration of light, 306
Abysmal deposits, 187
Acidic rocks, 142
Action of sea on rocks, 186
Active volcano, 157
Adhesion, 28
Air, temperature of, 211; thermometer, 50
Alabaster, 98
Alcohol thermometer, 50
Alluvium, 235
Altazimuth, 320
Altitude, 293
Ammonites, 265
Amplitude, 293
Analysis of water, 76
Angles, measurement of, 291
Angular measurement, use of, 291, 292, 293
Antarctic icebergs, 106; ocean, 195; temperatures, 197
Anticlinal curves, 152
Aphelion, 307
Aqueous rocks, 110,
Arctic ocean, 189
Aries, first point of, 293, 321
Artesian wells, 240
Atmosphere, 198; action of, 230; composition of, 199; density and pressure of, at different heights, 205; height of, 201; pressure of, 202
Atom, 27
Aurora Borealis, 289
Auroras, 289
Axis of the earth, 297
Azimuth, 293

Bar, 236
Barometer, 202; advantages of mercury for, 204; aneroid, 203; construction of, 203; corrections of, 210; glycerine, 204; height of, 207; water, 204
Barometric gradient, 256; pressure, variations of, 206; variations, relations of, to the state of the weather, 209
Barytes, 99
Basalt, 139
Basic rocks, 142
Basin, catchment, 232
Belemnites, 265
Black bulb thermometer, 53
Boulder, 251
Boyle's law, 36
Brash, 194
Breccia, 116
Breezes, land, 215; sea, 215
Brine springs, 241

Calcareous springs, 241
Calcite, 95
Calcium carbonate, 88, 95
Caloric, 45
Cañon, 233
Carbon, 77; dioxide, 78
Cardinal points, 277
Catchment basin, 232
Caverns, limestone, 132
Celestial globe, 329
Celestial latitude and longitude, 293
Celestial sphere, 296
Centigrade thermometer, 49
Chalk, 105
Chalybeate springs, 241
Chemical action, modes of, 82; affinity, 26; combination, laws of, 81; formulæ, 70; symbols, 70
Chemically formed rocks, 115, 131
Circle, graduated, 292
Circle, great and small, 291
Circumpolar stars, 302
Cirrus, 220
Classification of elements, 71
Clay, 118
Cleavage, 148
Climate, 257–262; changes of, 267; continental, 260; oceanic, 260; insular, 260
Clouds, 220
Coal, 104, 130; composition of, 130
Cohesion, 24, 25
Col, 234
Combustion, 74
Compass, variation of, 277, 290
Compound, 69; binary, 69; ternary, 69
Compounds, 79
Condensation, 62, 217
Conduction, 65, 67
Conglomerate, 116
Conservation of energy, 42
Contour lines, 255
Contraction of gases, 59
Convection, 65, 68
Coral, 107
Coral reefs, 125; formation of, 126
Crater, 164
Crevasses, 247, 253
Crinoidal limestone, 106
Crust, 84; earth's, section of, 264; action of sea on, 186; elements in, 102; minerals in, 102
Crystalline rocks, 114
Crystallisation, 30, 31
Culmination, 293
Cumulo-cirro-stratus, 220
Cumulus, 220

Darwin, 127
Day, longest, at different latitudes, 306

Day and night, length of, 306; variations in length of, 315
Days, different kinds of, 301, 309
Dead Sea, 133
Débris, 229
Decay, 74, 78
Declination, 293, 321
Degree, 290
Delta, formation, 236; lacustrine, 236
Deltas, examples of, 236
Density, 14; of earth, 154
Denudation, 153, 229; general results of, 254
Detritus, 229
Dew, 218
Dew-point, 218
Diamond, 101
Diatom ooze, 187
Diatoms, 177
Dip, 276; springs, 238
Disintegration, 186, 229
Distillation, 22, 217
Divisibility, 8
Dolomite, 97
Dormant volcano, 157
Dredging, 179
Drift ice, 190
Ductility, 34
Dykes, 136, 138, 254

EARTH, a great magnet, 274; a sphere, 294; axis of, 295; interior not fluid, 156; internal temperature of, 155; primitive condition of, 263; rotation of, 296; revolution of, 304; — proofs of, 302, 303; size and shape of, 296; sun views of, 316
Earthquakes, 168; causes of, 170; distribution of, 169; effects of, 171
Earth's crust, section of, 264; magnetic elements, 276; orbit, 300
Ebullition, 61
Eccentricity of orbit, 307
Ecliptic, 293, 310; plane of, 300
Elasticity, 35; of gases, 36
Electrical excitation, 279; induction, 282; machines, 283
Electricity, 278; atmospheric, 284; conductors and non-conductors of, 281; current or voltaic, 287; — — effects of, 288; kinds of, 280
Electrolysis, 288
Electro-magnet, 288
Elements, 69; number of, 71 in earth's crust, 102
Elevation, 172, 173
Encrinital limestone, 106
Energy, 39; examples of, 41
Equation of time, 309, 328
Equator, 297; plane of, 310
Equinoxes, 312, 310, determination of, 313
Erosion, 229; of rocks by glaciers, 249
Ether, 45
Evaporation, 11, 61, 216
Expansion, 54; of gases, 59; of liquids, 56; of solids, 55
Extension, 6
Extinct forms of life, 206
Extinct volcano, 157

FAHRENHEIT'S thermometer, 49
Felsite, 141
Felspar, 88, 93
Felstone, 141
Ferruginous springs, 241
Filtration, 9, 10
Firn, 246
Fissures, 247
Flint, 92
Floebergs, 194
Floes, 190, 194
Fogs, 219
Foraminifera, 105
Force, 14
Fossils, 265

GASES, 29
Geysers, 245
Glacial period, 266, 267
Glacières, 252
Glacier-mills, 249; table, 248; waters, 250
Glaciers, 246, 253; ancient, 251; erosion of rocks by, 249; motion of, 247; size of, 247
Globigerina ooze, 187, 188
Gneiss, 149
Gorges, 233
Gradient, 255; barometric, 256
Graduated circle, 290
Granite, 88, 140
Gravitation, 12, 14, 15, 16, 17, 18, 20, 21
Gulf stream, 183
Gypsum, 98, 134
Gyroscope, 302

HACHURES, 255
Hail, 227
Hardness, 37; scale of, 38
Heat, 44, 45; distribution on the earth of, 316; sources of, 46; and work, 47
Hoar frost, 218
Hydrogen, 75
Hygrometers, 200

ICE, barrier, 195; bay, 194; calf, 194; drift, 190; ground, 58; marine, 190, 192; pack, 190, 194; pancake, 194; sailing, 194
Icebergs, 193; Antarctic, 196
Ice-blink, 190
Ice-field, 190, 194
Ice-foot, 191
Ichthyosaurus, 265
Igneous rocks, 112, 136; classification of, 143
Impenetrability, 17
Inclination, 276
Inertia, 12
Intermittent springs, 243
Internal temperature of the earth, 155
Isobars, 208
Isoclinic lines, 276
Isogonal lines, 275
Isotherms, 213

KEPLER'S laws, 307
Kinetic energy, 40
Krakatoa, eruption of, 160

LACUSTRINE delta, 236
Land breezes, 215
Landslips, 244
Lapilli, 160
Latent heat, 60
Latitude, 297
Latitudes, high, 213; low, 213
Lava, 137, 138; streams, 161
Libra, point of, 293
Light, aberration of, 306; distribution on the earth of, 316
Lightning, 284
Limestone, 96, 105, 123, 145
Liquids, 29
Loam, 120
Lodestone, 268
Longitude, 297
Longitudinal valleys, 234

MAGNET, permanent, 272; temporary, 272
Magnetic needles, 270; induction, 272
Magnets and magnetic substances, 273; natural and artificial, 268; poles and neutral lines of, 269
Malleability, 33
Marble, 96, 124, 145
Mariner's compass, 277
Marl, 121
Mass, 14
Matter, definition of, 4
Maximum thermometer, 51
Mean solar day, 294; temperatures, 212

Measurement of angles, 290; of time, 294
Mercury thermometer, 50
Meridians, 93
Metallic elements, 71; veins, 90
Metamorphic rocks, 113, 144
Method of finding meridian, 300
Mica, 94
Micrometer, 327
Mineral springs, 241
Minerals, 89
Minimum thermometer, 51
Minute, 290
Mist, 219
Mixtures, 79
Molecule, 27
Momentum, 243
Moraines, 248, 249, 253
Moulins, 249
Murray on coral reefs, 128

NATURE, meaning of, 1
Needles, 186
Névé, 246
Niagara Falls, 233
Night and day, length of, 306
Non-crystalline rocks, 114
Non-metallic elements, 71, 72
Nimbus, 220
North-east passage, 189
North-west passage, 189
Nummulites, 266

OBLIQUITY of ecliptic, 313; change of, 315
Obsidian, 139
Ocean, colour of, 185; temperature of, 181–184; currents, 181; floor, depth of, 179, 180; form of, 180
Oceans, 175
Orbit of the earth, 307
Ores, 90
Organic rock materials, 103
Organically formed rocks, 115, 122
Oxidation, 73
Oxides, 73
Oxides of carbon, 78
Oxygen, 72

PACK ice, 190
Palæocrystic sea, 189, 194
Parallax, 306, 324
Pass, 234
Peat, 129
Pendulum, 292
Perched blocks, 251
Perihelion, 307
Petrifying springs, 132
Phenomena, 2
Physical and chemical changes, 80
Physiography, meaning of, 1, 3
Plane defined, 291
Plutonic rocks, 136, 140
Polar distance, 293
Polar lights, 289
Poles of magnet, 269; reciprocal action of, 271
Porosity, 9
Porphyritic granite, 140
Potential energy, 40
Potholes. 233
Precession, 325
Progress of life, 266
Properties, general and specific, 5
Pteropods, 187, 188
Pumice, 139, 160

QUARTZ, 88, 92
Quartzite, 146

RADIATION, 65, 66
Radiolaria, 177; ooze, 187, 188
Rain, 221; action of, 231; distribution of, 223
Rainfall, causes of, 223
Rain gauge, 222
Rainy seasons, 224
Raised beaches, 173
Ravines, 233
Reaction, 70
Refraction, 323, 329
Regelation, 57, 247
Regions of extreme dryness, 225; great rainfall, 225
Return shock, 285
Revolution of the earth, 297, 298, 299
Right ascension, 293
Rime, 218
River terraces, 235
Rivers, work of, 232
Roches moutonnées, 249
Rock, 85; formations, 264; periods, 264; salt, 100, 133
Rock-forming minerals, 91
Rocks, materials of, 86; position and arrangement of, 151; stratified, 108, 112, 264
Rotation and revolution, effects of, 301, 308
Rotation of the earth, 302

SALT lakes, 133
Sandstone, 87, 116, 117
Scoriæ, 137, 160
Sea, 175; action of, on earth's crust, 186; colour of, 185; depths of, 179, 180; temperature of, 181–184; breezes, 215
Sea-water, composition of, 176; density of, 178; frozen, 192; saltness of, 177
Seasons, 317; rainy, 224
Second, 290
Sedimentary rocks, 115, 116, 264
Selenite, 98
Shadow cast by the sun, 306
Shale, 116, 119
Sinter, 135
Slate, 147
Sleet, 227
Sludge, 194
Snakestones, 265
Snow, 226
Snow-line, 227
Soil, 150
Solids, 29
Solstices, 310; determination of, 313
Solution, 30, 31; saturated, 30
Sounding apparatus, 179
Soundings, 188
Specific capacity, 63; gravity, 22; gravities, tables of, 23; heat, 63
Sphere, celestial, 291
Sphere, definition of, 291
Springs, 237; brine, 241; calcareous, 241; chalybeate, 241; deep-seated, 239; dip, 238; ferruginous, 241; intermittent, 243; mineral, 241; submarine, 242; surface, 238; thermal, 241
Stalactites, 96, 132
Stalagmites, 96, 132
Stars, circumpolar, 302; daily appearance of, 303; yearly changes in appearances of, 310
Strain, 32
Strata, inclined, 152
Stratified rocks, 108, 112, 264; history of, 264
Stratus, 220
Streamers, 289
Stream-line, 255
Stress, 32
Striæ, 249
Submerged forests, 174
Subsidence, 172, 174
Sun, daily changes in appearance of, 304; diurnal changes of, 314; source of energy, 43; yearly changes in appearances of, 297; changes in declination and R. A. of, 312
Sun-dial, 295
Syenite, 140
Synclinal curves, 152
Synthesis of water, 76

TELESCOPES, 319
Temperature, 48; depends on height above sea-level, 214; horizontal distribution of, 214; of air, 211; of sea, 181,

182, 183, 184; relation of, to latitude, 213; vertical distribution of, 214
Temperatures, Antarctic, 197; deep sea, 183; mean, 212
Tenacity, 33
Terrigenous deposits, 187
Thermal springs, 241
Thermometer, 48; construction of, 49; uses of, 52
Thunder, 286
Time, equation of, 309
Time, measurement of, 292, 305
Torricellian vacuum, 203
Trachyte, 139
Transit circle, 322
Transverse valleys, 234
Travertine, 96, 132
Trilobite, 266
Tropics, 310

UNSTRATIFIED rocks, 109, 111, 112; classification of, 143

VALLEY-making, 233
Valleys, longitudinal, 234; transverse, 234
Variation, 275; diurnal, 275; secular, 275
Vernier, 326
Vertical, 19
Vertical, prime, 293
Volcanic ash, 160; ashes, 137; blocks, 160; bomb, 160; eruption, cause of, 162; — phenomena accompanying, 159; — products of, 160; — signs of, 158; mountains, structure of, 163; rocks, 136
Volcano, 157
Volcanoes, errors about, 165; number, position, and distribution of, 166
Voltaic electricity, 287; element or couple, 287
Volume, 14

WATER, chemical composition of, 76; expansion of, 57; specific heat of, 64
Water-parting, 232
Watershed, 232
Water vapour, estimation of, 200
Waters, glaciers, 250
Weather, 256; charts, 256
Weight, 13; atomic, 70; combining, 70
Wells, artesian, 240
Winds, 59; influence of prevailing, 261
Work, 39

YEAR, 317; civil, 317; sidereal, 317; tropical, 317

ZENITH, 291
Zenith distance, 293
Zodiac, 310; signs of, 310
Zones, 298

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6